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FORECASTING DROUGHTS AND ABNORMAL SEASONS*

Introduction

The disastrous droughts which have recently plagued Africa and Asia have brought to the forefront modern research work aimed at predicting them. The successful forecast of the unusually cold winter of 1976/77 in the United States of America has raised hopes that it might also become possible to predict unanticipated droughts and floods in developing countries. The object of this paper is to present facts leading to reasonable hopes, to make clear why some professionals believe future progress is possible, and to suggest what could be done to fulfil these expectations. The paper avoids technical details; rather it enumerates new and already available information, such as the observations gathered day and night by satellites over deserts and remote parts of oceans. It will mention a few striking facts that recent research has made known about the long-term behaviour of the weather and that sustain the hopes of experts concerning future prediction of weather. The paper ends with a brief review of the forecast of the severe winter of 1976/77.

The factors influencing weather presented here, such as "teleconnexions" and the role of the "maritime continent", are not necessarily the most important predictive tools used by the long-range forecasters. However, because they are striking, they can make the concerned public aware that meteorologists have begun to understand the long-range behaviour of the weather and give the layman as well as the meteorologist confidence in the future of prediction of abnormal seasons by scientific means.

The weather of the coming season is related to the temperature of the oceans and its anomalies[1]

The heat or energy of the sun, which in the final analysis is the cause of the daily weather and of severe or mild seasons, is not supplied directly to the atmosphere and converted into clouds, rain and weather, at least not on a large scale. It first hits the surface of the earth and of the oceans, where it is converted into low temperature heat. This degraded form of solar energy is the one which chiefly heats and energizes the atmosphere and is the cause of the clouds and the weather. The oceans play a fundamental part in the heating of the atmosphere and in causing anomalies of the weather and of the seasons, even in land-locked areas such as the Sahel and Afghanistan. The reason is that, on the one hand, the oceans cover three-quarters of the surface of the earth, and, on the other, they can accumulate enormous quantities of heat in the thick upper layers of the water, which they return slowly to the atmosphere over a period of weeks or months. The continents lose their heat to the air almost immediately, as they do not have the same capacity as the oceans for long-term heat accumulation. A decrease in temperature of 3 degrees Celsius, which would be insignificant in the atmosphere, results in the ocean in the release of vast quantities of heat and moisture which can influence the weather over a large area and for a whole season. Anomalies of temperature of the ocean, especially if they persist over several weeks or months, and over large areas, are related to the anomalies of the coming season, but not generally to the weather in their own area because of the so-called "teleconnexions", described in a following section.

Measurements of the temperature of the oceans, all over the world, are therefore very important for long-range forecasting of the seasons. Little was known about sea-surface temperatures before the era of satellites. The surface temperatures were measured by ships only along the sea lanes they normally plied, which covered only a small part of the huge surface of the seas. At present, complete up-to-date maps are available and drawn twice a day. The satellites survey rapidly the remotest parts of the oceans as easily by night as by day, because they are not based on visible light measurements but use invisible infra-red radiation for making accelerated movies which can trace the slow displacements of the currents of the seas.

The weather of the coming season is influenced by the conditions of the whole earth

The atmospheric disturbances which control the weather travel rapidly over continents and oceans at speeds which could enable them to circle the earth in hardly more than a week. The weather in the Sahara desert during the following season can therefore be influenced by conditions in very distant parts of the world. In order to predict correctly, the forecaster must be aware of the weather, and especially of the conditions which create the weather, such as the temperature of the oceans around the whole earth. Predicting tomorrow's weather in a small area of the Sahara desert does not require such global information. However, the long-range forecaster must watch the whole

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* By P.L. Schereschewsky, Former Director of the Meteorological Service of the Armed Forces of France. Reprinted from *Important for the future*, vol. III, No. 4 (September 1978), pp. 1-5, published by the United Nations Institute for Training and Research (UNITAR).

1 These anomolies were important in the successful forecast of the very severe 1976/77 winter in the United States, as will be seen at the end of this paper.

earth utilizing the necessary tools, satellites being the most valuable but not the only ones: they are now able to measure sea-surface temperatures, including the changing warm and cold currents, such as the Gulf Stream in the Atlantic Ocean, and abnormalities of the temperatures in the remotest corners of the seas.

The important role of the equatorial belt in seasonal anomalies

The geographic provinces of the oceans do not play equal parts in the heating of the atmosphere. In particular, the equatorial belt, which receives the major part of the solar heat, is the area which supplies the major part of the heat and generates the major part of the kinetic energy of the atmosphere. Within the troposphere, the most active agents that collect this heat and convert it into strong winds, rain and weather are the thunder-clouds or cumulonimbus. The cumulonimbus clouds are in fact the engines that run the atmosphere not only in the equatorial belt but, through the so-called meridional circulation, outside the tropical latitudes. They abound in the equatorial belt, gathered in groups called clusters or squall lines. The strong winds they generate and propel at various levels and at all latitudes, including the violent jet streams which circle the earth at high altitudes, react in turn on the ocean. They create the great currents (Gulf Stream, Kuro Shio, etc.), whose slow distortions contribute to the anomalies of the sea-surface temperatures mentioned above and are thus related to the anomalies of the seasons.

Importance of the Pacific Ocean and the maritime continent as a global influence on long-term weather

The various sectors of the equatorial belt do not play equal parts in the anomalies of the coming seasons. The Pacific Ocean sector clearly has more influence than its counterparts in the Atlantic and Indian oceans. This is not only because of its much greater surface and length (from Guayaquil in South America to Singapore and Sumatra in south-east Asia, it extends over one half of the surface of the earth) but also, and perhaps mainly, because of its temperature. The temperature anomaly of the Pacific water at the equator (compared to the mean equatorial water temperature) is both much warmer in the western Pacific ($+2^{\circ}C$) and much colder in the eastern Pacific ($-3^{\circ}C$) than in the Atlantic ($+1^{\circ}C$ to $-0.25^{\circ}C$). The Pacific may therefore be expected to be much more influential, as will be confirmed later.

The thunderstorms, while converting the latent heat of the air's moisture into the energy of the winds, produce large amounts of rain; the more energy they generate, the more rain falls. A fair estimate of the population of thunderstorms and of the energy the ocean imparts through them to the atmosphere can therefore be obtained simply by measuring the heaviest rainfall in the various parts of the oceans.

Before the era of satellites, rainfall over the oceans was only sporadically measured. No world maps were regularly available. How much energy was gained by the atmosphere from various provinces of the seas was not known, although it was an important element for the understanding of long-range anomalies of the weather. The Nimbus 5 satellite has greatly enhanced the available knowledge. The map for the year 1974 gives a striking and rather simple picture of the rainfall over the worl's oceans and of the global flow of energy from the oceans to the atmosphere. The prominent role of the Pacific Ocean, and of the equatorial belt in the Pacific Ocean, and of the equatorial belt in the western Pacific near south-east Asia, the so-called maritime continent, from Sumatra and Singapore to the Caroline Islands is immediately obvious. Compared to the rest of the world, south-east Asia appears as a unique concentration of intense rain, thus of powerful energy able to influence, through the teleconnexions and the jet streams, the climate and the seasons of remote areas. The 1974 map may not be completely typical, but it is unnecessary to delve here into technical features such as biannual rain cycles: the striking and simple aspect of the map remains generally correct.

Teleconnexions

The term "teleconnexions" refers to situations in which average weather conditions in two very distant areas are clearly and strongly correlated, a relationship which can be very helpful in long-range forecasting. For instance, when the average seasonal rainfall and the thunderstorm activity over the maritime continent in the northern winter season is above normal, the jet stream is, in turn, greatly reinforced over the western Pacific and sometimes all the way to the United States and Canada. There are some cases where this teleconnexion extends to Iceland and northern Europe. Consequently, unusual seasonal weather conditions in western Europe can, under these extreme circumstances, be related to an apparently small change in the seasonal water temperature over the faraway western Pacific. For example, an unusual blocking anticyclone between Iceland and Ireland has been observed instead of a normal southern anticyclone between Portugal and the Azores. The appearance along the west coast of South America of the disastrous warm current called El Nino, which severely reduces the catch of anchovies, seems also to be related to trans-Pacific interconnexions, namely to the patterns of easterly winds over the western and central Pacific.

The forecast of the severe winter of 1976/77 in the United States

The successful forecast of the severe winter of 1976/77 in the eastern United States was especially significant because the five preceding winters had been generally mild. This sharp change was explicitly announced as early as November 1976 and certain persistent anomalies in the surface temperatures of the

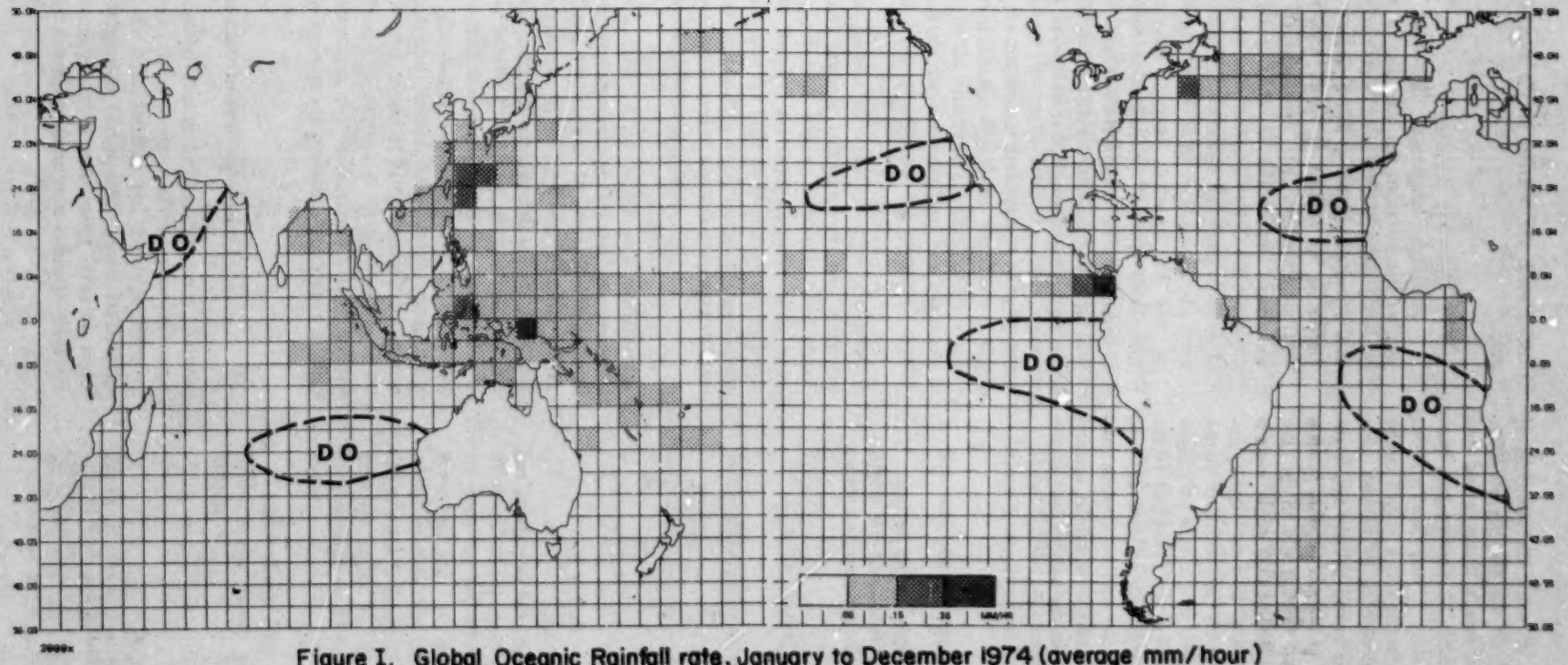

Figure I. Global Oceanic Rainfall rate, January to December 1974 (average mm/hour)

Note : The annual rainfall over the oceans, which is related to the energy supplied by the oceans to the atmosphere, shows a single and strong world maximum over South East Asia, which suggests that this area plays a special role in the life of the atmosphere. The map indicates also, in contrast, the oceanic areas (within dashed lines, marked D O) where annual rainfall is as low as over the continental deserts (Sahara, Kalahari, Australia, etc.) according to the map of Professor Rudolf Geiger.

Pacific Ocean had already attracted the attention of the forecasters at the end of the summer of 1976. Without going into technical details, it can be said that the ocean near the west coast of America had been warmer than average for rather a long time, while at the same time the central Pacific Ocean stayed colder than average. This enhanced contrast in the area occupied by the polar front was bound to have important long-term consequences if, as seemed possible in view of its duration, it continued through the winter. The consequences included a northward shift of the eastern Pacific polar front perturbations into the Arctic, followed by strong invasions of very cold Arctic air masses into the eastern United States, producing snow instead of rain. The cold of Arctic origin was reinforced by the reflective power of the snow-cover, which, in turn, facilitated the expansion of the cold air invasion into the south-eastern United States. In short, an unusual and severe winter prevailed in the eastern half of the nation while the weather on the west coast remained mild.

Conclusion

Although long-range forecasting of seasonal weather has attracted the attention of meteorologists for many years, it is still in fact a new branch of science, with a limited number of active persons. As long-range forecasting of seasons is vitally important to many developing nations, their meteorological services have an unusual opportunity to catch up rapidly with the developed nations in a useful and exciting field and to offer an original and valuable contribution to the progress of meteorology, while benefiting themselves. If, as may be expected, seasonal forecasting becomes sufficiently reliable, this suggestion may even become a necessity. The United Nations and its agencies, as well as several developed nations, can efficiently assist the developing nations in that endeavour.

SMALL HYDRO STATIONS: A SENSE OF URGENCY*

Before the increase in oil prices and the subsequent world-wide energy crisis of 1973, many large thermal power plants were built in the industrialized nations because of their low construction cost and the abundant supply of fossil fuel. Also, hydroelectric power plants gradually became large not only in the developed countries but also in the developing countries, a result of economies of scale.

Particularly in a large electric supply system, a large pumped-storage station is the most economical and the easiest method of storing the low-cost energy of thermal and atomic power plants, while producing valuable energy for peak loads. In Japan, however, because of the continuous development of hydro power stations, economically favourable sites have gradually diminished. In the meantime, the demand for water by industries, farms and municipalities has continued to grow as the Japanese economy has progressed rapidly.

The utilization of water resources has therefore been directed towards redevelopment and integrated development of river basins. Thus, the small run-of-river power stations are being replaced with multi-purpose dams that are built in combination with hydro power plants, particularly with pumped-storage stations. This tendency has helped to alleviate the power shortage in the cities and industrialized areas.

On the other hand, small- and medium-scale hydro power projects have generally not been developed because of the high initial investment cost and the limited contribution to the large energy supply system. A great many rural and remote areas and small communities hardly benefit at all from electrification and are therefore socio-economically under-developed. Nevertheless, at the initial stage of development, several isolated small and medium hydroelectric projects did contribute to the raising of living standards by improving educational facilities and to the modernizing of the Japanese economy. So these projects may indicate that a large hydropower project is not always superior to a small one.

The role and importance of mini-hydro

The energy crisis in 1973 caused many countries to research and develop new possible sources of energy, since each year costs increase and the stable supply of fossil fuel diminishes. Consequently, until the development and completion of new energy systems, hydro development should be taken into intensive consideration.

Generally, large-scale hydropower stations require more environmental considerations and a longer construction period than small ones. Also, in the tropical regions, the problem of water-related diseases spreading by large storage reservoirs must always be carefully considered. Smaller plants have little effect on the environment because of the small intake dam with either a small or no reservoir, a short and narrow tunnel, and open channel or penstock and a compact and small head tank or powerhouse.

Mini-plants are also more effective than large ones in saving fuel since their annual operating time is about 5,000-6,000 hours, while that of the large-scale plants is usually about 1,000-3,000 hours.

Economic study of the small-scale hydro plant

The critical economic equivalent condition between the small-scale plant and the oil-fired thermal power station is approximately expressed by:

$$K_h\alpha_h + p_h/W_h = K_t\alpha_t + p_t C/W_t \qquad (1)$$

The capital recovery factor is:

$$i(1+i)^n/[(1+i)^n - 1] \qquad (2)$$

The annual fuel cost is:

$$\beta_s W_t \qquad (3)$$

Let us assume that, in equations (1), (2) and (3), n is 45 years for the small hydroelectric power station and 20 years for the oil-fired thermal power stations; i is 6 per cent and 7 per cent; β is about 0.22 1/kWh under condition that the efficiency factor of the thermal power plant is about 39 per cent; p_h and p_t are approximately equal; W_h and W_t are both 5,600 kWh/kW corresponding to 69 per cent of the installation capacity factor.

Accordingly, the economical limit of the small hydroelectric power projects may be expressed as follows:

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* By N. Sasaki, Assistant Chief of Hydropower Division, Agency of Natural Resources and Energy, Ministry of International Trade and Industry, Japan, and T. Yasuda, Managing Director, Chuo Kaihatsu Corporation, Japan. Reprinted, with permission, from *Water Power and Dam Construction*, vol. 31, No. 1 (January 1979), pp. 31-33.

In the case of 7 per cent:

$$K_h = 1.28K_t + 16{,}800s \quad (4)$$

In the case of 6 per cent:

$$K_h = 1.35K_t + 19{,}040s \quad (5)$$

Assuming that K_t is about 100,000 yen/kW and s is about 35 yen/litre, as of 1977 in Japan, then

K_h will be 716,000 yen/kW from equation (4) or 801,000 from equation (5).

If s would increase to 45 yen/l, then K_h should become 884,000 yen/kW and 992,000 yen/kW respectively.

In Japan, the capital installation cost per kW for a small hydroelectric power project is about 600,000 yen/kW to 888,000 yen/kW at present. Consequently, many planned hydroelectric power projects are becoming economically feasible. Given the cost escalation of fossil fuel and security in domestic energy sources, the development of small hydroelectric power projects is most important and urgently necessary.

Notations

K = installation cost per kW

p = associated transmission line cost, annual taxes, operation and maintenance cost, and others

W = annual energy produced per kW

α = capital recovery factor

C = annual fuel cost in yen

i = annual interest rate

n = years of estimated life

β = fuel consumption per kWh

s = fuel cost per litre

Suffixes h and t represent small hydro and oil-fired thermal stations respectively.

Potential hydro energy in Japan

The potential for hydroelectric energy has to be developed further; Japan has reached an advanced stage compared with other countries, except for Western Europe..

Since 1910, research and investigation on potential hydroelectric energy have been carried out by government agencies in five major studies. The estimated potential energy was increased in each case because of changing criteria: the electricity supply system, conditions of demand, technological progress of civil and electrical engineering and economic conditions (table 1).

Table 1. Estimated hydro potential in Japan

Study period	*Potential energy (MW)*		
	Developed	*Planned*	*Total*
1. 1910-1913	480	2 940	3 420
2. 1918-1922	1 030	6 400	7 430
3. 1937-1941	6 566	13 474	20 040
4. 1951-1955	8 755	13 779	22 534
5. 1956-1959	10 816	24 554	35 370
This study 1976	24 363	31 518	55 881

On the other hand, the total installed capacity of hydroelectric power stations in Japan, as of March 1977, was only 35,820 MW, including 9,870 MW at present under construction. This total is approximately 22 per cent of the total capacity of power-generating stations, including thermal and atomic power stations.

The planned potential of small hydroelectric power projects (i.e., with a maximum capacity of 300 kW-10 MW) is shown in table 2.

Table 2. Potential energy from small-scale hydro schemes

	Number of projects	*Installed capacity (MW)*	*Annual production of energy (MWh)*	*MWh/kW*
Small-scale	1 930	4 161	21 733	5 223
Large-scale	410	27 357	37 422	1 368
Total	2 340	31 518	59 155	1 877

These small-scale hydro projects are generally classified into three categories:

(*a*) Small discharge project with a medium or high head over 50 m;

(*b*) Medium discharge project with a medium head;

(*c*) Large discharge project with a low head of 4-20 m.

The large-scale project consists of several types of power station, except the pure pumping station, and includes only the river's equivalent energy capacity for combined pumping stations.

In this study, potential energy sources are summarized. Several existing reports and data have been used without site investigation. Moreover, the potential energy of small-scale projects totalling 4,160 MW, as shown in table 2, was considered too small because of the limited number of these low-head projects and their remote locations. However, if such projects are included, judging from a number of sources, the feasible potential energy for small hydro stations might be estimated to be at a higher level, i.e., around 10,000 MW.

Cost reduction study for the small plant

Generally, the construction cost of electromechanical equipment of a hydropower station represents about 16-25 per cent of the total construction cost, and this percentage becomes inversely proportional to the scale of the project. Thus, any cost reduction on electromechanical equipment could have an enormous influence on the total construction cost of small-scale hydro plants, as well as cost reduction of civil works.

Usually hydro-generating equipment is manufactured according to the specifications prepared for the respective power stations. Therefore, the construction cost of electromechanical equipment is higher than that of standardized or mass-produced equipment. If the electromechanical equipment for hydro stations could be standardized and mass produced, it could contribute to a reduction in the total construction cost.

One method of standardizing the hydraulic turbine is the proposed standard turbine unit chart, shown in figure II. With given effective heads (m), discharges (m^3/s), and corresponding to installed capacity (kW) of given planned hydro projects, the rotational speed of the turbine n (rev/min) and the diameter of the runner D (m), which can be designed and calculated for effective heads, discharges and capacity, were plotted.

In order to consider the characteristics of hydro projects, an adequate block area was selected. This is indicated by hatched lines in figure II. It was determined that the hydraulic turbines of hydroelectric projects, with given effective heads and discharges that lie in a block area in the H-Q curve of figure II, have the same design and could be standardized for the purpose of reducing construction costs.

Originally, the capacity of a generator depended on the product of the diameter of stator (D_i), the length of rotor core (L_i) and the rotating speed n. Here, in the range of a constant dimension of D_i, it is possible to design a standard unit generator by adjusting L_i in accordance with the unit capacity.

As shown in figure III, GD^2 (momentum) depends on the unit capacity of the standardized method mentioned. If it is necessary to add additional momentum to the turbine requirements, it is possible to incorporate an additional flywheel or to admit a large value of momentary speed to rise at a sudden load rejection.

We reviewed and checked the specification of the hydromechanical equipment taking its high reliability into account. The main aims were to minimize necessary conditions, establishing a basic layout, reduction of accessories, simple and easy maintenance and operation, and consequently to achieve a reduction in construction costs with these various options:

Turbine

- utilization of the most economical material;
- adoption of a fixed blade propeller runner;
- eliminating guide vanes;
- adoption of dry bearings;
- adoption of an induction generator to omit the governor on the turbine;
- adoption of a propeller type turbine to increase rated speed;
- adoption of a special type of automatic speed regulating device.

Generator

- adoption of an induction generator;
- adoption of a synchronous generator with brushless a.c. exciter;
- adoption of a class F insulation for the stator coil;
- adoption of an open type, self-ventilated cooling system for the generator;
- selection of the most economical terminal voltage.

Conclusions and recommendations

A research programme to determine potential hydroelectric energy is urgently needed, using a country-wide and systematic approach. The estimate of feasible potential energy of mini-hydro plants of about 10,000 MW, including low-head projects, should be completed during the next ten years, within a construction cost of about 5,000 billion yen.

Energy produced by small plants should be sold through the existing distribution grid system in principle and utilized for a rural development programme as follows: household electrification, electricity-generating facilities for fish ponds, electricity supply for social and recreation facilities such as medical, health, cultural and educational centres, and the promotion of rural electrification for livestock, lumber mills, agriculture and agro-based industries.

Finally, although Japan's electric power utility is covered by nine private electricity companies and one electric power development company, small-scale plants should be administered by local public organizations, such as the agricultural, forestry and fishery associations throughout Japan. It should be possible in this way to reflect the rural characteristics and to obtain the consensus and participation of the rural inhabitants.

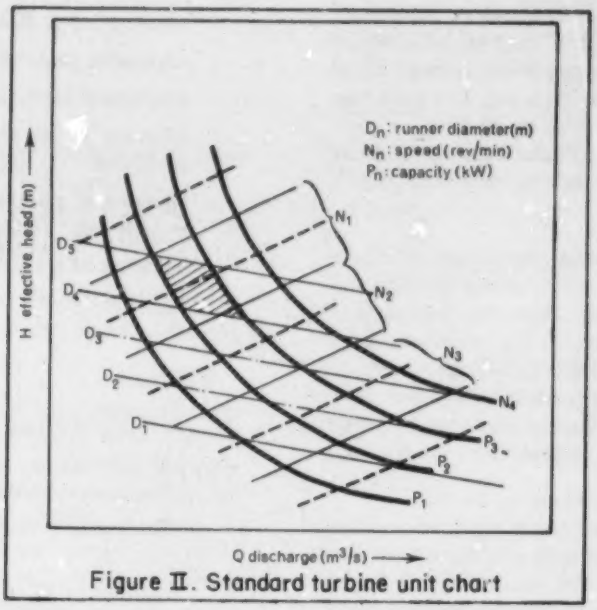

Figure II. Standard turbine unit chart

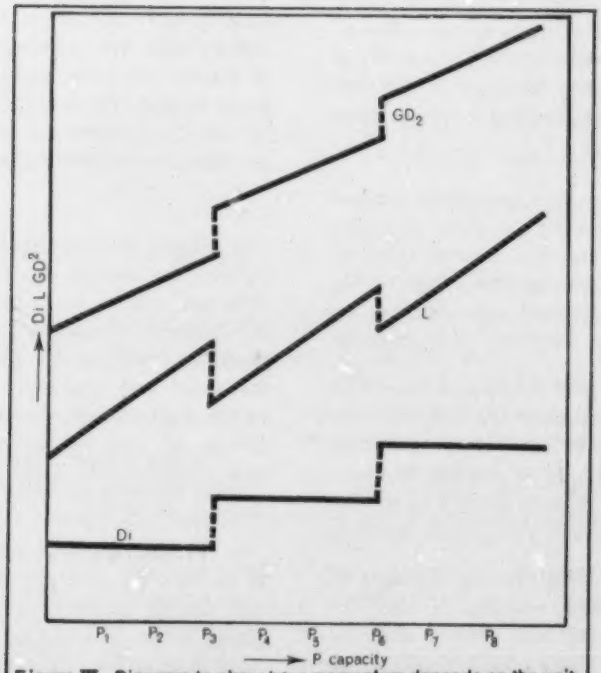

Figure III. Diagram to show how momentum depends on the unit capacity according to the standardized method described

THE ECONOMICS OF SMALL HYDRO*

Uncertainties about the future availability and cost of fuels have caused renewed interest in non-fuel-dependent energy sources. Some of the most promising of these are the numerous underveloped small hydro sources which are available in the United States today. As an example, a stream flow of 14 m^3/sec at heads in the range of 6-9 m is sufficient to sustain a hydro-electric generation capacity of 600 to 1,000 kW. Even on smaller streams, plants of such capacities could be operated for a few hours of peaking generation daily, with relatively small upstream storage capability.

On a slightly larger scale, a 35 per cent capacity factor plant of say 10,000 kW capacity and 9 m head would probably require an average annual river flow of over 84 m^3/sec, which is fairly substantial.

In general, then, the major potential for new peaking power hydro plants on previously undeveloped sites is probably, on smaller rivers, capable of sustaining installations of 5,000 kW or less. The lower limit of size of installation, which most municipal groups or co-operatives would consider as an alternative to the other available power sources, is probably about 500 kW, provided impoundment, access and transmission facilities can be readily and economically obtained.

In the past few years, hydroelectric development has been hampered by a number of problems. For base load applications with high capacity factors, such plants are required to be sited on relatively large rivers or reservoirs to obtain the necessary head and year-round flow availability. The benefits of economy of scale, low long-term operating costs and non-dependency on the availability of fuels, which have in the past favoured hydro installations, have been overshadowed by high initial investment costs and problems arising from environmental concerns and the lengthy periods now required for planning, design, licensing and construction.

Even for peaking applications, hydroelectric developments may take as long as six to eight years to implement, particularly if environmental objections prolong the process. Uncertainties in peak load forecasting since the oil crisis of 1973 have led to reluctance on the part of utilities to embark on major long-term capital investment programmes for peaking power, when gas turbine units can be brought on line in as little as two years for an appreciably lower investment cost.

Present possibilities

Existing hydro developments with relatively small reservoirs would have minimal environmental impact, but at current price levels can cost anything from $US 700 to $2,000 per kW of installed capacity, or even higher at sites where the costs of reservoir impoundment are relatively high. On the other hand, in the north-east of the United States alone there are more than 2,600 existing dams and reservoirs without power-generating facilities. Many of these could be developed with minor environmental impact - in some cases for less than $700 per kW. In the case of developments at existing reservoirs, the availability of head and flow will dictate the installed capacity from a low of 500 kW up to 15,000 kW, or even as high as several hundred megawatts in some instances.

Cost comparisons

At current cost levels for fuels, the average total annual fixed cost, plus variable costs for hydroelectric developments, does not compare favourably with fuel-dependent sources. However, a rapid escalation of fuel costs would cause hydroelectric energy, which is currently uneconomic, to become more competitive in five to ten years' time. Such a time frame is compatible with the period currently required to design, license and construct a hydroelectric plant.

Quoted plant and fuel costs vary, but figure IV shows that hydro is at present competitive with oil-fired peaking and mid-range (combined cycle) options only at capacity factors greater than about 35 per cent. The coalfired alternative using western low-sulphur coal (not shown) is similar in cost to low sulphur oil-fired plants. The equivalent energy cost for gas turbines is shown for a range of fuel costs based on both current prices and a 5 per cent increase. Hydro costs are representative of complete developments with from 500-15,000 kW installed capacity and heads up to 15.2 m, ranging from $700-1,500 per installed kW. These would currently be considered reasonably attainable for new installations with environmentally acceptable reservoirs, heads of 6-9 m generally being the least likely to provoke serious controversy.

Costs of developments at existing reservoirs would be expected to be somewhat less in terms of composite cents per kWh of annual energy generation. The economic potential for hydro installations at such sites is currently the focus of concerted research and development programmes being sponsored by federal government agencies.

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* Based on an article by J.D. Lawrence, Manager, Hydroelectric Projects, Acres American incorporated. Reprinted, with permission, from *Water Power and Dam Construction*, vol. 31, No. 1 (January 1979), pp. 33-36. This article originally appeared in *Public Power*.

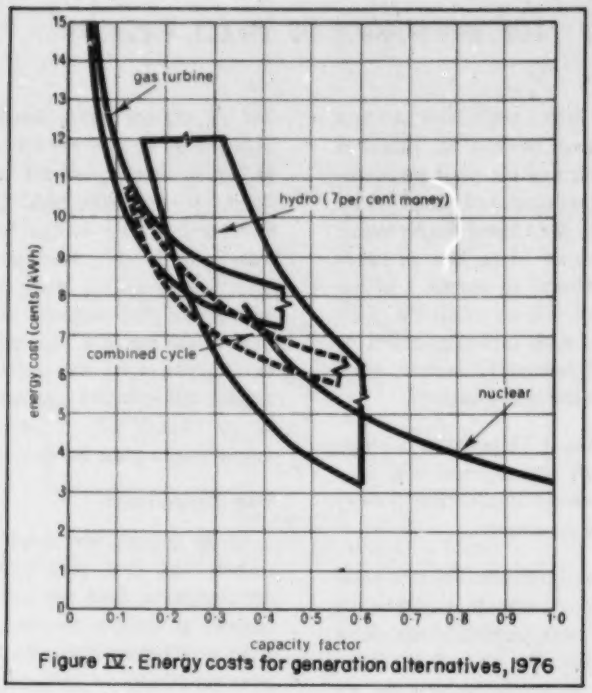

Figure IV. Energy costs for generation alternatives, 1976

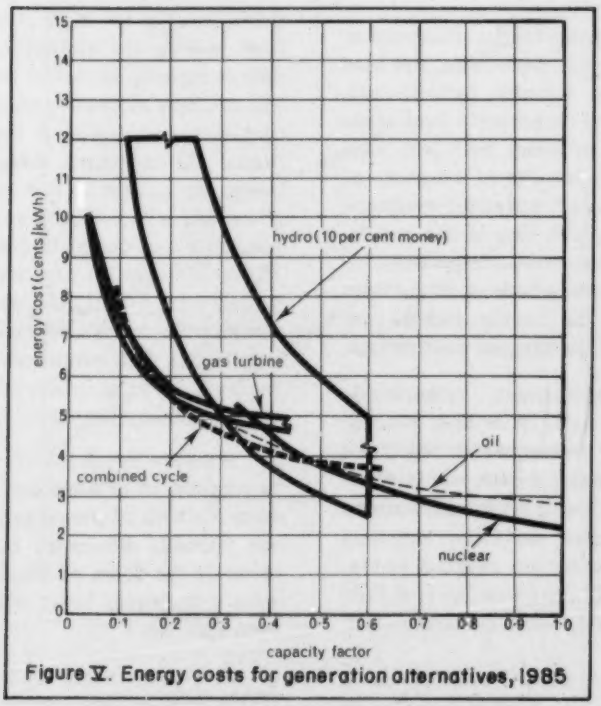

Figure V. Energy costs for generation alternatives, 1985

Cost assessments favour thermal developments

In view of the uncertainties of predicting future costs, power generation options are usually evaluated at current levels for both capital and operating costs. This practice has usually favoured thermal developments, which generally have lower investment and higher operating costs.

A report by the Corps of Engineers published by the Institute for Water Resources in July 1975 identified the need for re-examining the present practices of projecting costs at current levels for both the hydro and thermal alternatives, and for adopting assumptions as to future rates of inflation in all project costs and benefits, and in the general level of prices.

Prediction of future fuel costs is a hazardous venture, but it is reasonable to assume that fuel prices will continue to rise faster than prices of other commodities. Figure V illustrates an example in 1985 in which all costs are escalated from current levels at a uniform 5 per cent per annum. Band widths are also shown for the combined cycle and gas turbine alternatives in which the fuel cost components are escalated at 7 per cent.

Assuming federal funds are made available for economic developments, hydro costs are based on 1976 levels of $700-1,500/kW financed at 7 per cent and escalated at 5 per cent per annum. It is again apparent that hydro plants currently costing $700/kW will be competitive at 20 to 25 per cent capacity factor. These are quite conservative assumptions; consideration of project life cycle costs in which fuel costs continued to escalate would obviously favour the hydroelectric option. More realistic cases can easily be drawn in which peaking hydro developments, with capacity factors of less than 20 per cent and costing $1,000-1,500/kW are more economic than the thermal options. In addition, concentrated efforts are being made throughout the industry to investigate a number of potential economies in hydro plant design. The cost of reservoirs, dams and waterways is generally the highest component, amounting, on average, to nearly half the total. Except in the cases where existing dams are available for use, there would appear to be little scope for reducing the cost in this area if safety standards are not to be impaired.

Nevertheless, it is evident that long high impounding structures should be avoided, both from the cost and from the environmental standpoint. Natural head differences over relatively short distances should be exploited whenever possible. Wide shallow reservoirs, populated areas, agricultural land, wetlands and areas of historic, recreational or scenic interest are generally not favourable for development.

Savings in power plants

Greater potential exists for cost reductions in the supply and installation of power plant equipment which has generally comprised about 30 per cent of the total development cost.

An economy measure which is already receiving attention is the use of unmanned stations. For a given river, with seasonal flow variations, the economic design of a hydro installation has traditionally involved the evaluation of the optimum solution in terms of reservoir size, dam height and head variation, turbine-generator unit numbers, sizes and characteristics and the system power and energy demand. In the past, this has generally resulted in selection of unique unit designs for most projects, each requiring considerable expenditure in design and production development and frequently homologous model testing of equipment. Operating requirements have also generally been restrictively conservative and relatively costly.

Equipment suppliers now have available units design templates and production facilities for a wide range of turbines and generators which could be readily manufactured. It would seem logical, therefore, not to concentrate on optimizing the equipment design to suit a given case, but rather to select from an inventory an available unit design which best fits that situation in terms of maximized benefits at minimum cost. There are indications that cost savings of as much as $200-300/kW of installed capacity could be achieved by a number of methods such as this.

Consideration should also be given to taking full advantage of built-in overspeed capacity and excluding automatic shutdown facilities. Fail-safe design approaches and use of induction generators would allow significant cost reductions. The exclusion of adjustable wicket gates and blades on propeller-type turbines may also be economically justified by restricting the operation of a plant to a fairly narrow head range with automatic (water-level controlled) flow-closure gates.

Another area in which there is obvious potential for savings in hydroelectric plant costs is in a modular approach to powerplant design in terms of standardized electrical and mechanical equipment and also, to a lesser extent, in the civil/structural design. Manufacturers should be able to reduce costs appreciably if a market can be found for relatively small standardized components of hydroelectric equipment such as turbines, generators and associated auxiliaries.

The manufacturer of complete "off-the-shelf" equipment packages would not only contribute to reduced production costs but also offer utilities additional cost-saving potential in terms of accelerated installation schedules.

There is clear evidence that both publicly owned and private utilities are keenly aware of the improving economics of small hydroelectric developments. Forecasts of increasing scarcity of fuels in the 1980s would suggest that it is none too early to initiate studies not only of potential hydroelectric sites, but also of methods of reducing the high investment costs of such installations.

MINI-HYDRO DEVELOPMENTS FOR REMOTE AREAS*

Mini-hydro or micro-hydro are loose terms which generally describe very small projects which either supply a special load, such as gate hoisting machinery at a remote storage dam, or a small load centre in an isolated region. Sizes can typically range from a minimum of 10 kW to about 5,000 kW, while heads vary from 1.5 to 610 m.

The mini-hydro concept has found widespread acceptance in many parts of the world, primarily for providing electric power sources at locations not serviced by transmission from larger or conventional generation centres. It is interesting to note that in China, some 2,000 MW of power are generated from over 60,000 plants with installed capacities ranging from 20 to 50 kW.

In essence, the mini-hydro plant is conventional in all respects, except perhaps in the uses for which it is selected. Because of its inevitably high cost, it will only be considered as an alternative to diesel generation to supply an isolated load. Furthermore, it will often only be economic where diesel fuel costs are high because of fuel transportation charges.

Application

In general, mini-hydro plants may be considered for small isolated loads where the alternative is diesel generation. Because the civil costs associated with such plants are higher, compared with the electrical and mechanical costs, than for larger scale hydro, the total capital cost tends to be high. Also, transmission from the generation site to the load is almost always involved. Nevertheless, by comparison, diesel fuel costs in remote areas are very high, both because of the basic fuel cost, but more importantly because of transportation costs which often exceed the basic fuel price at the nearest railhead. Accordingly, while the criteria for economic hydro interconnected to a grid usually require generation from 10 to 25 mil/kWh, the mini-hydro station in a remote area may provide significant direct cost economies over alternative diesel, even if its generation costs are in the order of 60-100 mil/kWh.

Because of present high fuel costs and the prospect of continued price escalation, a mini-hydro project can provide significant long-term benefits, if a suitable site can be located. It can also provide three major advantages:

(a) It is simple to operate;

(b) No fuel cost or fuel transport problems are involved;

(c) It is reliable and requires minimal maintenance.

As the mini-hydro project will only consist of very small structures, there is virtually no question about its technical or engineering feasibility at any site, providing adequate flow and head are available. Its selection is therefore entirely a question of its generation cost compared with alternative diesel.

Since the major portion of the capital cost of the hydro project is potentially a dam for diversion and possibly storage, the economics of a project may be improved significantly if storage is not needed, so that only a low diversion weir is provided. The most appropriate site will therefore have a minimum available river flow in excess of the plant requirements.

Factors affecting the economics of mini-hydro

If the alternative to hydro is taken to be diesel generation, then the maximum or break-even cost of the hydro installation is relatively fixed for any given general area. Since the capital cost of a diesel unit is small compared with the total generation cost, this ceiling break-even cost is similar for both new diesel installations and existing units where fuel saving only is being considered.

The cost of generation from the hydro station, however, is virtually entirely a function of the capital cost of the plant; this, in turn, is primarily affected by the cost of the civil works. While the total electrical and mechanical equipment cost of the station is largely fixed in the $350-600/kW range, the total cost of the station may range up to, say, $2,500/kW and still be economic, with the balance of the cost being made up by civil works. These include diversion dam or weir, canal (if required), penstock and powerhouse structure.

The size and cost of the diversion dam or weir is a function of the topography of the diversion site. If storage is required to compensate for the natural flow regime of the river, then additional dam height, and hence cost, will be entailed. Consequently, for simplicity of operation and to minimize the dam height requirements, it is preferable to have a site with a sufficient river flow during the dry period to meet generation requirements without providing additional storage.

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* By R.M. King, Senior Hydro Engineer, Shawinigan Engineering Company, Montreal, Canada. Reprinted, with permission from *Water Power and Dam Construction*, vol. 31, No. 1 (January 1979), pp. 38-41.

The cost of the powerhouse structure for a small installation is primarily dependent on the size and number of the turbine-generator sets.

A further major factor is the distance between the site and the load centre, since transmission costs can be significant. The economic viability of the small hydro installation is therefore largely dependent on the availability of a suitable site in terms of availability of flow, width of the river section at the diversion point, river slope and hence distance over which the head has to be concentrated and distance from the load centre.

Operating ranges

There is no formal definition of mini-hydro in terms of head ranges or power outputs; however, in this context, one is usually considering generation for isolated loads which would typically be less than 1,000 kW. At this size, it is usually economic to consider special designs for hydro generation, first, in terms of standard packages that include turbines, generators, control and electrical equipment, and secondly, for special turbine designs since the cost per kW of conventional equipment increases rapidly as heads decrease below 9.1 m.

One application is the Ossberger cross-flow turbine, of which more than 5,000 have been built. This unit can be specified for a wide range of flows and heads and can operate efficiently over widely ranging flows. Ossberger turbines are available for flow ranges of 0.028 to 7.03 m/sec and head ranges of 0.9 to 200 m. Depending on the combination of head and flow, turbines are available for outputs of up to about 2,000 hp. Individual station outputs can, of course, be increased by using multiple units.

An important consideration in the layout and equipment selection for the hydro scheme is the pattern of the daily load curve and the range between maximum and minimum loads that must be supplied.

An isolated primarily domestic type load will probably have an over-all load factor of about 30-50 per cent. Night-time loads will be very low in any case, and particularly so where electrical power is not used for heating or 24-hour equipment operation. To some extent, the load variation will be limited in a centre where power is only supplied during the day, as is often the case. Nevertheless, ideally, the plant should be able to provide generation to meet a wide variation in power demands. This could well dictate using more than one turbine for flexibility and special consideration in selecting the transmission facilities. A further factor to be noted is that, for an isolated load, it is necessary to provide synchronous rather than induction type generators.

Generation costs

Generation costs for either a mini-hydro scheme or a diesel plant will vary with plant size, load factor, location (for diesel), site conditions (hydro), and distance from the load centre (hydro).

Because site conditions radically affect the cost of the hydro scheme, it is not practical to consider hydro costs on the basis of a typical plant. However, diesel generation costs may be developed with reasonable accuracy, for a range of load factors and fuel prices, and these may be used to develop maximum or break-even hydro capital costs, i.e., capital costs for which the cost of hydro generation is equal to that from alternative diesel.

Maximum or break-even costs have been developed for a 370 kW (500 hp) installation; these are described in the following hypothetical comparison.

Diesel generation cost. The capital cost for a single 370 kW unit, including civil works, switchboard, installation, fuel storage, access, etc., would be in the order of $140,000.

The fuel cost could vary from $0.50/gal (imperial) at a railhead location to $1.00/gal in a remote area where fuel has to be brought in by air transport in 40 gal drums. The fuel would be distillate No. 2.

Plant service life is assumed to be 20 years. Generation costs are shown for a series of annual plant capacity factors and for fuel prices of $0.50, $0.75 and $1.00/gal, including transport. The interest rate is assumed as 10 per cent. The annual charges would be as follows:

Interest (10 per cent)	$ 14,000
Depreciation	2,500
Operation and maintenance	40,000
Administration	10,000
Insurance	400
Interim replacement	400
Total	$ 67,300

The variable costs per kWh would be:

Fuel cost ($/gal)	*Variable energy cost ($/kWh)*
0.50	0.030
0.75	0.045
1.00	0.060

The total diesel unit generation costs are shown in figure VIa. These are the sum of the fixed cost (fixed annual charges divided by annual generation) and variable or fuel cost. The total generation costs are as shown in the table.

Generation costs for diesel plant in dollars/kWh would be:

Capacity factor (per cent)	Annual output (million kWh)	Generation costs when fuel cost is: $0.50/gal	$0.75/gal	$1.00/gal
		(per kWh)		
40	1.3	0.082	0.097	0.112
50	1.6	0.072	0.087	0.102
60	1.9	0.065	0.080	0.095
70	2.3	0.059	0.074	0.089

Break-even hydro capital costs. The corresponding hydro capital break-even costs are obtained by deriving the capital cost which, together with annual operating costs, will provide an equivalent unit generation cost.

The total annual hydro costs are made up of interest, depreciation, operation and maintenance, administration, interim replacement and insurance.

For this example, the annual operation and maintenance cost, plus administration cost, is assumed at $25,000, the interest is taken as 10 per cent and depreciation is applied over 20 years. The sum of the annual costs, exclusive of operation, maintenance and administration, is approximately 12 per cent of the capital cost.

The derived break-even hydro costs are shown in figure VIb, for a range of annual plant capacity factors and fuel prices. As can be seen, the maximum break-even costs on a $/kW basis range from $1,850/kW for 40 per cent capacity factor operation, with fuel at $0.50/gal, to $4,100/kW at a capacity factor of 70 per cent and a fuel cost of $1.00/gal.

It may be considered that the hydro alternative should provide some significant advantage over diesel to compensate for the higher capital outlay and the relatively higher uncertainty over the hydro capital costs.

If the minimum benefit to cost ratio, or ratio of the relative costs of diesel versus hydro, is taken as 1.5 (i.e., the generation cost from diesel is 150 per cent of that from hydro) to establish firmly the merits of the hydro option, then the maximum break-even capital costs would be reduced to those shown in figure VIc. The range in maximum hydro capital costs would then be between $1,040/kW at 40 per cent capacity factor and $0.50/gal and $2,550/kW at 70 per cent capacity factor and $1.00/gal fuel cost.

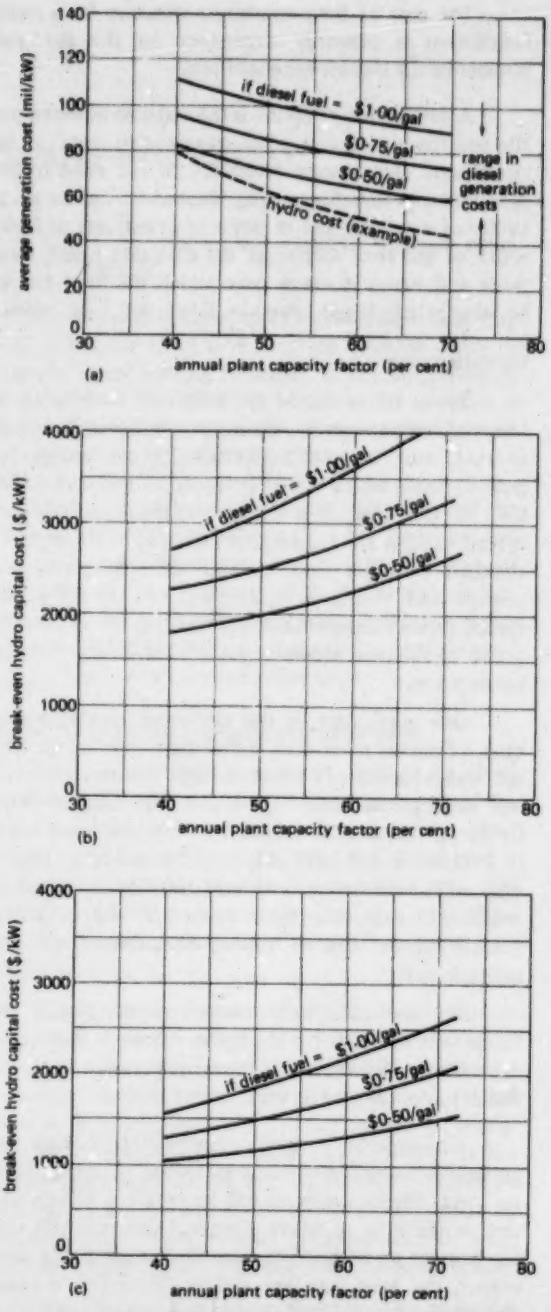

Figure VI. (a) Comparison of generation costs for hydro and diesel; (b) break-even costs for hydro assuming a benefit/cost ratio of 1.00; and (c) as for (b) but assuming a benefit/cost ratio of 1.50. The example is based on a single 370 kW (500 h.p.) unit

Hydro generation costs

The above figures provide a general indication of the maximum capital costs for which a mini-hydro project will be feasible.

The actual capital cost of a hydro project will largely depend on the site conditions and the scheme layout required to develop the site. The relative importance of the components of a typical hydro scheme may be illustrated by the following example, which is based on the hypothetical scheme shown in figure VII. This scheme would have an installation of 500 hp or 370 kW operating under a 15 m head, and would use a a firm or guaranteed flow of 7.83 m^3/sec with no storage being required. This hypothetical scheme would

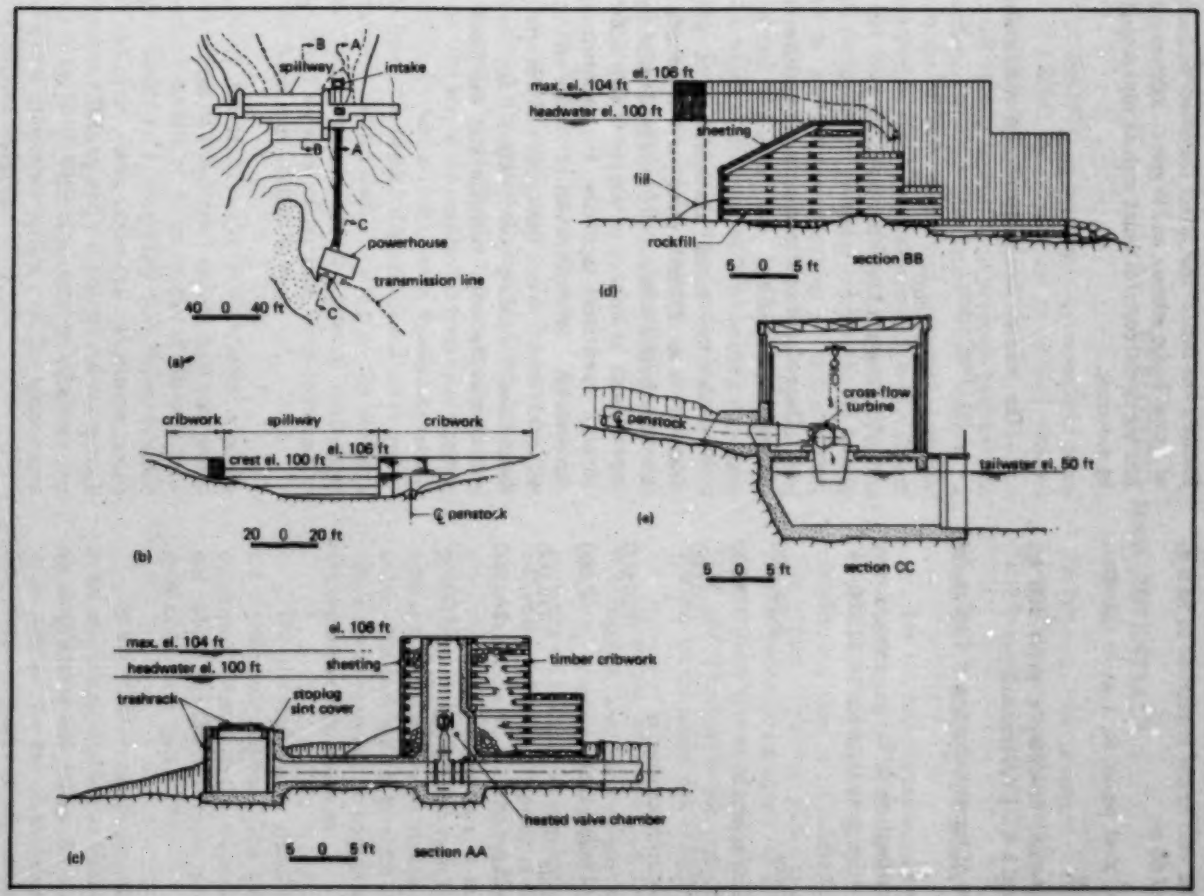

Figure VII. Typical arrangement of a mini hydro scheme (a run of river scheme without storage), showing : (a) overall plan; (b) downstream elevation; (c) section through the power intake; (d) section through the spillway; and (e) section through the power-house. Dimensions are based on a single 370 kW unit, operating under a gross head of 50 ft (15 m).

consist of a diversion weir, penstock and powerhouse as follows:

(a) An overflow diversion dam made with a timber crib section. The dam height is assumed to be 6 m with a crest length of 60 m;

(b) A buried steel penstock, 1 m in diameter, with a length of 60 m;

(c) A powerhouse, including a single 500 hp cross-flow turbine and a 400 kVA generator;

(d) Three km of transmission line at 4 kV to the load centre.

The corresponding capital costs, using a very approximate order of magnitude, would be $1,800/kW, as follows:

Dam and spillway	$ 200,000
Penstock (150 m in length)	78,000
Powerhouse (civil)	60,000
Turbine/generator/miscellaneous equipment	150,000
Transmission (2 mile-3 km)	40,000
Total direct costs	528,000
Indirect costs 25 per cent	132,000
Total	$ 660,000

Economic feasibility

The foregoing comparison has been provided to illustrate the factors that affect the economic feasibility of a small hydro scheme, and to give an indication of the limiting capital costs for which such a hydro project may be economic.

The primary factors in the cost comparison are:

(a) Fuel price;

(b) Load factor;

(c) Margin of benefits over costs.

These all potentially have the same relative impact on the economics of a project.

While the initial assessment of a project's feasibility is usually made purely on cost grounds, there are other factors such as fuel source (and hence negative aspects such as balance of payments and security of supply), operational simplicity, low maintenance and environmental concerns, which all require serious consideration in such a comparison, and which in effect may be included in deciding to what degree, if any, the hydro project may be more economic than the diesel alternative.

EXPLOITING DAM POTENTIAL*

In mid-1974, an investigation was made to determine the feasibility of creating an isolated pumped storage system near the centre of utilization, as opposed to a location near an existing or proposed hydroelectric installation. Such an installation would require the preparation of both surface and underground storage. At the time of the original investigation, such a project was not feasible, if one considered the use of conventional pump-turbine generator components. In seeking means to improve the economics of such a system, research led to the consideration of the application of an old and proven art - the hydraulic air compressor (HAC), which uses a head of water as the compressing medium. Consideration of the advances in gas turbines over the past two decades prompted an investigation into the combination HAC and gas turbine generator as a power source.

The HAC was first used about 100 years ago, the first patent being granted to J.P. Frizell in October 1880. During the period 1890-1910, numerous installations were made in the United States, Canada and Europe. The last of the large installations dates from the late 1920s, by which time units in smaller size were in use in India. The demise of the HACs was not caused by any inherent shortcoming, but rather by the advent of cheap electric power and the internal combustion engine. Even so, some of the HAC units continued to perform for periods of 40 to 50 years.

Every significant water impoundment is potentially a source of compressed air which, if used with a gas turbine instead of its conventional adiabatic compressor, results in a completely new thermodynamic cycle. This cycle, having isothermal compression, results in improved efficiency and can only be realized through the use of the HAC. While HACs offer no advantage over the adiabatic compressor in first cost, the maintenance requirements are negligible.

The greatest advantage to be gained by using the proposed combination is that from two to four times as much power can be generated compared with a conventional hydraulic turbine for the same flow rate. While it is true that additional fossil fuel must be supplied to the gas turbine, the uniqueness of the thermodynamic cycle reduces this requirement to 50-60 per cent of the fuel required by a conventional gas turbine generator, while driving its own compressor for the same output.

Depending on factors such as water supply and topography, the combination of HAC-gas-turbine generator is applicable to existing hydroelectric instal lations, either at dams or pumped storage stations. Furthermore, the increased output, economy and adaptability to remote control make many more locations economically feasible.

Discussion of the combined system

The standard gas turbine power-generating facility consists primarily of an adiabatic compressor supplying air at 5-12 atmospheres pressure to a combustion chamber and then to an adiabatic expansion turbine. This turbine supplies the power to drive the compressor and the excess power drives the attached generator. In the combined system, the compressed air is supplied by HAC and the whole of the turbine output is therefore available for the production of useful power.

It should be noted that the characteristics of the standard and combination systems differ considerably. Consider the standard gas turbine generator operating on a simple Brayton cycle. For each allowable maximum operating temperature there is an optimum operating pressure. With the materials currently available, this optimum pressure is in the range of 8-12 atmospheres. If the pressure ratio is increased above the optimum, the total power output decreases. In contrast, in the combined system, in which the turbine no longer drives the compressor, the output continues to increase as the pressure ratio increases.

The thermodynamic cycles in the two systems are considerably different. The HAC is an isothermal compressor, therefore the thermodynamic cycle does not follow the Brayton cycle but rather the Norton cycle as shown in figure VIII.

It is evident on comparison that the Norton cycle is the equivalent of adding an infinite number of adiabatic compression and intercooler stages to the Brayton cycle without the use of this expedient. The results, of course, are greater power output and fuel economy with reduced first cost.

Also characteristic of the HAC is the fact that the compressed air has a reduced oxygen content, the amount being dependent on the compression ratio. The compressed air is also saturated with moisture, which when expanded in the combustion chamber adds to the power generated. These two characteristics have a cancelling effect.

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* By J.R. Norton, Head of General Engineering, Oklahoma State University, and C.R. Huddleston, consultant, Houston Texas. Reprinted, with permission, from *Water Power and Dam Construction*, vol. 31, No. 1 (January 1979), pp. 36-38.

The bibliography lists books giving a detailed description of hydraulic air compressors. The following brief explanation should provide an understanding of the principle of operation.

Water enters the HAC from an elevated source into a tank section which may or may not be provided with added air entrainment devices, as shown in figure IX. This tank section rests on a vertical fall tube, and as water flows down this tube it entrains air. The fall tube terminates in an enclosure called the air-water separator. In this vessel the water velocity is greatly reduced and its direction of flow reversed. The separated air rises to the top of the separator and the water flows up a riser to the exit level. Therefore, for a continuous flow of water one has a continuous supply of compressed air at a pressure determined by the design compression head.

It is of interest to note further that the HAC has no moving parts, requires substantially no maintenance, operates at an isothermal efficiency of 85-95 per cent in large sizes and has an almost unlimited life. Since the topography of most locations means that part of the fall tube and the air separator must be underground, these installations will involve considerable structural and concrete work above the ground and generally excavation and mining underground. The result is that the cost of an HAC is comparable to that of the adiabatic compressor it replaces. An over-all system savings is realized because the turbine size is reduced by the amount required for air compression. This savings is not only in first cost but also in fuel costs and maintenance.

The combination system lends itself to the added refinements associated with the standard turbine, i.e., regeneration is applicable to reduce fuel requirements further. No gain is to be realized from multiple compressors and intercoolers because the air is compressed isothermally.

While not stated explicitly, the primary objective of the proposed HAC-gas-turbine generator system is the conservation of natural resources at a time when provision of energy in the most economical form is of paramount importance. As will become evident, from two to four times as much power can be expected from the volume of water flowing through the combination cycle as would be produced by the same amount of water flowing through a conventional hydraulic turbine. To realize this increase, however, the addition of a fossil fuel is necessary from one- half to two- thirds that required by the standard gas-turbine cycle producing the same power output.

Considering the multitude of hydroelectric installations in operation and those this system would make feasible, one can easily visualize an increase of at least twice the total power generation from water resources. The published statement that hydroelectric power sources will decrease from 8 to 5 per cent of the nation's total energy output can be reversed to reflect a gain.

System illustration

In the following example, only comparative results of calculations will be presented, which should not be construed as design calculations. No allowance will be made for the difference in compressor efficiencies, and the turbines and generators will be assumed to be indentically efficient.

Consider applying the combination cycle to an existing dam producing hydroelecuric power from a pool with an average head of 36.6 m. Based on an assumed flow of 0.03 m^3/sec, the total output power for the system can be determined from the allowable flow rate. For the above conditions, the power produced by a hydraulic turbine operating at 100 per cent efficiency will be 13.61 h.p. or 10.16 kW.

If the head available is reduced to 35 m to allow for tailrace fluctuation, it will entrain and compress approximately 0.04 m^3 of air for each cubic metre of water flowing. To match commonly used gas turbine pressures, a compression ratio of 10 to 1 is assumed. To provide this 10 atmospheres pressure will require a compression head of about 100 m, making the fall tube length about 137 m. This is approximately the depth of the excavation required for the air separator.

Assuming that the maximum allowable temperature at the turbine entrance is 926°C, the 0.04 m^3/sec of air at 10 atmospheres will produce a combined cycle output of 46.07 or 34.37 kW. This is 3.38 times the hydraulic turbine output. The gas turbine will require 7 mil/kWh, based on $10.00 per barrel fuel oil. To produce the same output from a standard gas turbine cycle would necessitate a turbine of 46.37 hp, requiring 13 mil kWh for fuel.

Conclusions

From the preceding, we can conclude that from 0.03 m^3/sec of water flowing under the conditions stated we can generate 10.16 kW of electrical energy. The same amount of water flowing through the HAC-gas turbine will produce 0.04 m^3/sec of air at 10 atmospheres pressure which will produce 34.37 kW, or an increase by a factor of nearly 3.4. The fuel required to produce this added output will only be 58 per cent of that required to produce the same output from a standard gas turbine for the conditions assumed.

Hence, we have a combination system in which all of the components are standard and readily available. A knowledge of the requirements and design criteria of the intake section, fall tube, air separator and riser for the hydraulic compressor is necessary in any design of a combination HAC-gas-turbine generator system. The characteristics of the compressor under operating conditions must be matched to the operating characteristics of the gas turbine. The calculations have been the subject of intensive research over the past year.

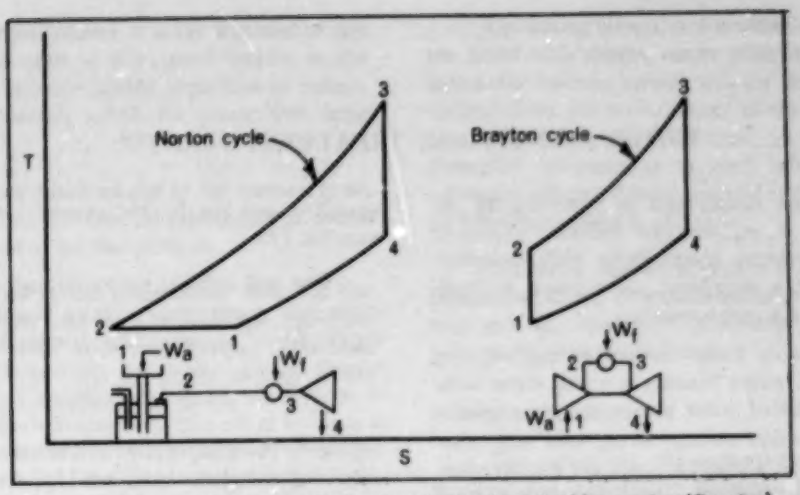

Figure VIII. Thermodynamic cycles for the standard gas turbine system (Brayton), and for the combined system (Norton), where air is supplied by a hydraulic compressor

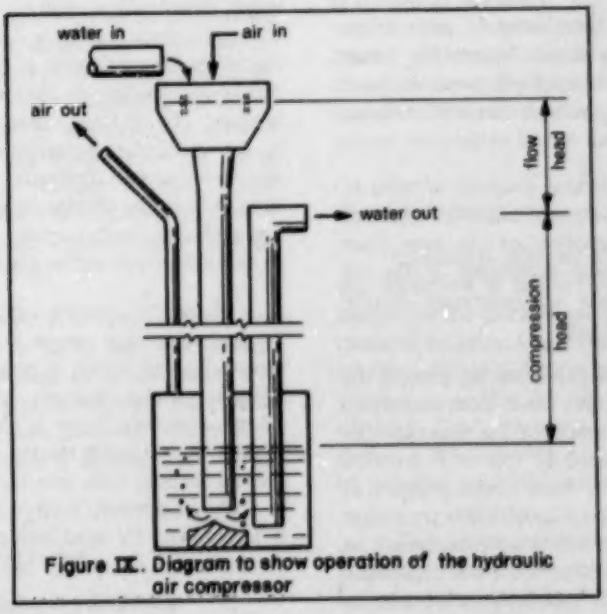

Figure IX. Diagram to show operation of the hydraulic air compressor

Considering the amount of hydroelectric power now being generated, if one-third were converted to the combined system, the total electric output derived from water sources could be increased over 2.5 times and the converted output would still be available for peaking or emergency use. In view of these potential gains, it behoves each hydroelectric plant owner to give serious consideration to conversion to the combination HAC-gas-turbine cycle.

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WATER AND SEWAGE TREATMENT PLANTS*

As the major constituents in paper-making are wood pulp and water, the new effluent treatment plant of the Wycombe Marsh Paper Mills described below will make a significant contribution to both paper-making and the environment.

A new building forms an integral part of the effluent treatment plant, housing a pump room with sludge pumps, clarified water pumps and air compressors/dryers, a chemical storage/mixing area with associated dosing pumps, a chlorine room and a plant room with basic working facilities. These include the main control panel, chlorine residual recorder and frequency modulator for controlling the chemical additions in proportion to the variable flow.

The installation has been designed with ample capacity for expansion and allows for possible future installation of secondary treatment plant, such as sand filtration, to improve the quality of the effluent even further.

In addition to the obvious financial benefits of reducing the abstraction and disposal bills with increased recirculation, the semi-automation of the new plant removes the need for manual desludging of the old rectangular beds, which was an extremely labour-intensive and very unpleasant job.

As a vital part of the paper-making process the company abstracts potable grade water from underlying aquifers and uses it in all aspects of the paper-making process at a rate of approximately 181 m^3/h (40,000 gal/h). The effluent produced from this is pumped to crude sedimentation tanks where liquid/solids separation occurs. Up to May 1978 the solids were discharged to landfill sites and the "clarified" effluent was discharged to the River Wye. Owing to increasing environmental pressures, the company then began discharging the solids to Little Marlow sewage treatment works for further treatment.

The company is charged for each cubic metre unit according to its quality (measured as settleable solids and dissolved organic content).

With the increasing costs of water abstraction and now the additional cost of effluent discharge, it was decided to improve the existing treatment installations and attempt to produce a water of re-usable quality, aiming to recycle up to 75 per cent.

Consultants were engaged and various treatment specialists were approached, and the turnkey contract was finally awarded to Degremont Laing Ltd – an amalgamation of the French-based water treatment specialists and the British company John Laing Construction Ltd.

The mill effluent passes through a magnetic flow meter into a rectangular mixing chamber of approximately 30 m^3 capacity. This chamber is equipped with a small mixing turbine and caustic soda addition point to increase the pH to 7.0 if required (acidic pH control is achieved in the mill by automatic dosing of aluminium sulphate). The pH-corrected effluent overflows into the centre of the main unit, a 13 m diameter, circular, turbine-assisted clarifier known as a turbocirculator of 400 m^3 capacity.

A flocculating aid is added and the incoming water, mixed with a small amount of recirculated sludge, is evenly distributed in a downward direction, causing the solids to settle onto a conical base and the supernatant to overflow at the periphery, into a collecting launder. The clarified water is then chlorinated to act as (a) a disinfectant/biocide and (b) a de-colourizer/bleach for certain dyestuffs, before entering a series of large rectangular storage tanks (the old settling beds) from where it can be pumped back to the mill for re-use, or excess overflow can be discharged to the sewer.

A slowly rotating bridge mechanism on top of the turbocirculator moves the sludge at the base into a central hopper, which is periodically desludged into an adjacent extract chamber (rectangular, approximately 17 m^3 capacity). There is also a scum removal facility to deal with floating matter. The sludge is piped across the old settling beds into the existing dewatering plant (a string-discharged, rotary-vacuum filter), from where it is removed by road transport, at approximately 25 per cent solids content, to landfill sites.

Description of a turbocirculator

The turbocirculator is a sludge blanket clarifier of the type in which sludge is circulated continuously from the clarification zone, through a reaction zone, where it combines with floc particles forming in the incoming water as a result of upstream chemical treatment. The result of this action is that the growth of the floc is accelerated, so that settlement takes place readily in the clarification zone to maintain a homogeneous sludge blanket.

A circulator clarifier of conventional design relies on the energy of the incoming water to achieve the sludge circulation and is therefore limited in flow rate

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* Reprinted, with permission, from *Water Services*, vol. 83, No. 996 (February 1979), pp. 75-77.

variation. The turbocirculator is a development of this design and incorporates a slow speed turbine in the reaction zone to circulate sludge, regardless of inflow, and is therefore ideally suited for plants with large variations in load.

Additional chemicals are fed to the reaction zone, as necessary, and in this case polyelectrolyte is added to assist coagulation of the floc particles.

Sludge settles in the clarification zone and the floor scrapers, driven from the rotating bridge, move the sludge to the centre collecting trough. Additional scrapers are fitted to keep the sludge moving in the trough and to thicken it prior to discharge.

The sludge discharge system includes an automatic valve, timber-controlled, and the discharge periods and intervals are set in such a way that the sludge condition is optimized in order to maintain a substantially constant amount of sludge in the turbocirculator. It is necessary to maintain both the scraper bridge and turbine in service at all times, even when there is no inflow, to prevent complete settlement of the sludge. This is primarily to avoid solids carry over, following the resumption of inflow, and also to prevent blockage of the sludge discharge system. In addition, provision is made for recirculation of the sludge from the pump sump to the turbocirculator to cater for zero inflow conditions and to give a measure of shut-down capability for the vacuum filtration plant, without risk of blockage in the sludge discharge pipework.

Supernatant is collected in a launder at the top of the turbocirculator via a baffle and weir system. The baffles prevent the passage of surface scum and debris to the launder and a surface scraper attached to the rotating bridge directs these impurities to a collection hopper and chute where it is discharged to the sludge pump sump.

Chemical dosing

Aluminium sulphate and sulphuric acid dosing

Dosing facilities are provided at the mill for preconditioning effluent, by the addition of either aluminium sulphate or sulphuric acid to reduce the pH when necessary to about 7 or less. Since, however, there is normally sufficient aluminium sulphate in the effluent divided from the paper-making process to ensure flocculation, it is normally only necessary to add acid for this purpose.

Caustic soda dosing

It is necessary, at certain periods, to correct pH upward and equipment for this purpose is housed in the new chemical building. Caustic soda is received at site in containers and is in the form of a 47 per cent solution. The containers are placed in a bunded area for connexion to the adjacent dosing pumps.

The dosing pumps, one working and one standby, are fitted with manual stroke positioners and with an automatic by-pass system on the delivery pipework controlled by pH measurement at the top of the plant inlet mixing chamber. In addition, the pumps are speed-controlled proportional to plant inlet flow and the combined effects of these controls ensure that there are no large fluctuations in pH.

The entire pipework system is electrically trace-heated and lagged to avoid freezing of the caustic solution and the necessary connections are provided for pump calibration and flushing.

Polyelectrolyte dosing

The equipment for polyelectrolyte dosing was supplied and installed by Wycombe Marsh Paper Mills and is housed in the chemical building (See figure X). A solution is prepared in a mixing and aging tank and then transferred by gravity to a pumping tank, where it is diluted as necessary. The solution is drawn from the tank by one of two dosing pumps fitted with manual stroke positioners and speed-controlled proportional to plant flow. Provision is made at the plant inlet chamber for visual checking of the flow, and the dosing system terminates in the turbocirculator reaction zone.

Chlorine dosing

Chlorine is delivered to site in pressurized cycliners and connected to headers in two banks, each of six cylinders, in the chlorine room, which is attached to the chemical building. Gas leaving the cycliners is controlled by one of two chlorinators, which releases gas under vacuum according to the demands of the manually adjusted flow regulators. An automatic changeover device is incorporated to switch to the standby bank of cylinders when the gas in the duty units is exhausted.

Two dosing points are provided, one at the turbocirculator outlet and one at the mill recycle pump delivery line, each fitted with an ejector powered by motive water. The injection to the turbocirculator outlet is cut off automatically when the plant inflow is stopped, but manual regulation of the dose is necessary to maintain an acceptable chlorine residual at the outlet of the existing settling tanks.

The dosing point at the mill recycle pump delivery is supplied continuously when either pump is running with a manually controlled nominal dose and, at intervals controlled by a timer, with a preset additional shock dose to ensure that the recycle pipework is cleared of any build-up on the walls. Motive water in this case is supplied via a booster pump, which starts and stops with the duty mill recycle pump.

Equipment for the chlorine plant includes a space heater, extraction fan and safety masks for the operators for use when cylinders are changed.

The positioning of the ejectors ensures that only gas under vacuum conditions is transmitted from the chlorinators up to the injection points and a fracture in these lines will automatically cut off the gas flow. The possibility of leakage of highly chlorinated water is also reduced to a minimum.

Compressed air equipment

Two cylinder-mounted air compressors of the oil-lubricated type are provided, one duty with automatic standby and with provision for duty rotation. Air is supplied from the receiver via an oil removal filter, air dryer, after filter and pressure regulator. The air dryer is of the auto changeover, electrically heated, regenerative desiccant type to ensure moisture free air to a dew point of - 40°C.

Control and instrumentation systems

Flow is measured at the plant inlet by a magnetic unit and the signal used to indicate flow on the control panel in the chemical building. The signal is also used to set the output of a frequency converter, which supplies power to the caustic and polyelectrolyte dosing pumps, giving motor speed variations proportional to plant flow.

A solenoid valve in the chlorine gas line to the turbocirculator outlet is controlled on/off by the inlet flow signal, to avoid the possibility of highly chlorinated water being discharged to the outlet pipework at low or zero flow conditions, if the operator fails to regulate the gas supply.

The pH is measured at the top of the inlet mixing chamber and the signal used to control the volume of caustic soda delivered to the base of the chamber in conjunction with a preset timer and by-pass control value. At pH values of 6 or less, the caustic dose is continuous at a rate governed by the pump stroke positioner and motor speed. At pH values 6 to 6.7 approximately, the by-pass valve opens intermittently, in accordance with the timer settings, and at pH values above 6.7, the by-pass opens continuously, effectively cutting off the dose. The pH is measured at the turbocirculator outlet and indicated on the control panel as a final check on the effluent passing to the setting tanks.

The sludge discharge control system consists of an adjustable timer for both discharge time and interval. This timer is panel-mounted local to the sludge pump sump. The sludge transfer and recirculating pumps are level-controlled but, in the event of failure of either the discharge system or the pump controls, the sludge level in the sump would equalize with the top water level in the turbocirculator. The system is fail safe.

A continuous sample system from the outlet of the settling tanks is used to record the free chlorine residual in the effluent passing to the sewer or to the mill recycle pumps. This system incorporates a high residual alarm.

Shock dosing of chlorine to the mill recycle pump delivery is controlled by a local, panel-mounted, adjustable timer in conjunction with a solenoid valve in the gas line. Since the motive water booster pump is interlocked with the mill recycle pump starters, it is only possible to dose chlorine to the delivery line when the duty recycle pump is operational. Chlorine flow is indicated on each of the three manually adjusted regulators.

All pumps in the plant, with the exception of the sludge transfer pumps and chlorine booster pump, are manually started and stopped. The scraper bridge drive and turbine are also manually controlled, but a safety switch is incorporated in the bridge drive control circuit to trip the supply in the event of the scraper arms jamming.

Safety equipment

A shower unit is available in the event of the plant operators being involved with a spillage of chemicals, particularly caustic soda, and with sulphuric acid, if this equipment is installed eventually. The operators should be equipped with protective clothing, goggles and helmets as recommended by ICI when working in the chemical area.

Before entering the chlorine room, the operators must switch on the extraction fan and should not attempt to change gas cylinders without wearing a safety mask. In the event of a major leak, e.g., breakage of a valve on a gas cyclinder, the operators should evacuate the area immediately, since the safety masks are only designed to give short-term protection. Full breathing apparatus is necessary for entry to deal with major leaks.

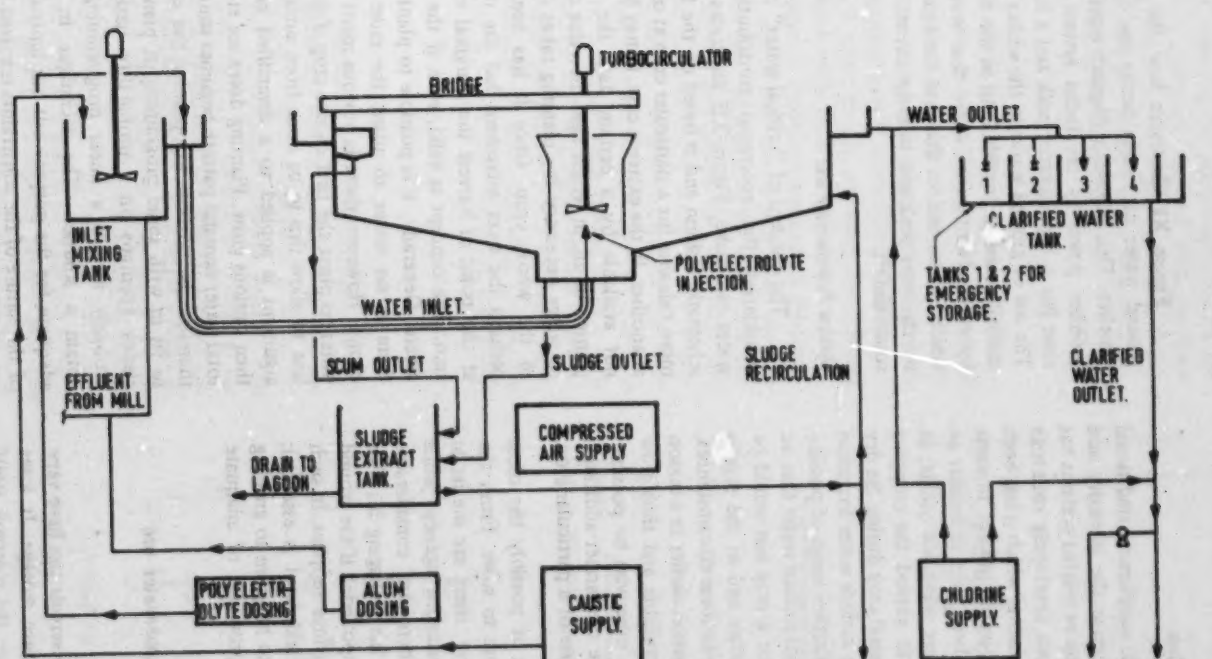

Figure X. Flow diagram showing the complete treatment process at Wycombe Marsh Paper Mills

CONJUNCTIVE USE OF SURFACE AND GROUND WATER SUPPLIES*

Introduction

The use of ground water to supplement traditional surface water resources to increase the intensity and area cropped in existing irrigation or rainfed systems has been increasing rapidly in various developing countries over the past 15 years. The manner in which it has been used varies considerably from project to project. In some rainfed areas, ground water has been used to bolster an erratic rainfall in order to ensure adequate yields; in other cases, it has been used to extend the cropping season or even to grow an additional crop during the dry season. Integration with existing surface water irrigation systems immediately suggests a further range of possibilities, such as the use of additional surface water that on its own would be insufficient for a crop but would be adequate if supplemented, at either end of the season or at the peak, by ground water. In these circumstances, it may also be used to start irrigation earlier in a season before surface water becomes available and thus grow a higher value crop than would otherwise be possible. Such crop diversification can give the farmer additional insurance against the risk of failure of a particular crop.

The management problem is possibly the most difficult and controversial problem to solve. From the point of view of the total reserve, there are merits in over-all management by a government agency, while from the farmer's viewpoint there are considerable advantages to be obtained from his managing his own water supply. The dilemma is compounded if the ground water is of poorer quality than surface supplies. In such a case, careful management at field level is essential; special consideration may have to be given to growing salt-tolerant crops and to the provision of adequate leaching water.

Some advantages of ground-water use

Storage and flexibility of supply

The use of a ground-water reservoir can have very considerable advantages over surface storage. It loses virtually no water by evaporation; the reservoir itself is natural and requires no capital expenditure and the development costs in terms of wells are low. More importantly, a well can be in operation within days of construction, whereas surface works often take years. The use of ground water is very flexible; it can be pumped when needed and left alone when not. As long as there is a long-term balance, the aquifer can be overpumped in years of short surface supply and allowed to recover in years of abundance. All these things are possible, provided that management is adequate.

Figure XI illustrates how the judicious use of ground water can make better use of existing surface supplies. This schematic diagram represents the kind of problem posed by the Indus system in Pakistan. The river has a high summer peak and a low winter supply. The use of ground water in the winter months can substantially raise the usable limit in the summer and thereby take advantage of water that would otherwise be wasted to the sea. In this case, the aquifer is replenished by the river peak and to some extent by summer monsoon rainfall.

Optimal conjuctive use

The concept of "critical water" can be of value in considering the enormous contribution that ground water can make. Figure XII illustrates the principle in schematic fashion and is based on the fact that water is more valuable for a particular crop at one time than it is at another. In the extreme case, it may be that if water is not available by a certain date the crop cannot be planted at all, in which case the value of the increment of water necessary for planting takes on the net value of the whole crop. Once it has been planted, then perhaps the next increment has the most value until at the point of harvest the marginal value of water is zero. The concept is valid, even if the extreme case is severe. Generally, it is possible to plant another crop if there is no water to plant the most profitable first choice. However, there is obvious merit in using ground water to plant the first choice crop if the river rises too late to allow this to be done from surface water. If the argument is applied to a diversified cropping system, then options grow. Planting dates are staggered and the total water demand pattern becomes smoother. It should therefore be possible to optimize the cropping pattern to fit in with some programme of planned water deficiency (perhaps on a probability basis). This would probably involve a linear programming technique to obtain a solution. The technique in itself is quite adequate for the purpose but our limited understanding of the nature of the constraints involved has, in the past, led to anomalous results.

To some extent, the argument is academic in the Indus plains, where the irrigation system is already in

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* By R.F. Stoner, Sir M. MacDonald and Partners, Cambridge, United Kingdom. Reprinted, with permission, from International Commission on Irrigation and Drainage (ICID), *Bulletin*, vol. 27, No. 2 (July 1978), pp. 65-67. This paper was presented at the Overseas Development Institute Workshop on Choices in Irrigation Management, held at the University of Kent, Canterbury, from 27 September to 1 October 1976.

existence and is working at an annual intensity of about 100 per cent. With all our planned intensification actually implemented, the intensity would not exceed 150 per cent or so.[1] With these relatively low intensities, the farmer has the option either to use a full water supply or to spread. With really low intensities, he tends to spread at the moment, but when new projects are implemented, in a presently irrigated area, he does appear at first to use more water on his existing crops. Later, as he gets used to handling larger areas of crop, he may try spreading his water further again.

Soil salinity

A further factor in this argument, which is particularly relevant to the Indus plains, is the problem of soil salinity. If water is spread too thinly, the soils will certainly go saline and it is normal to allow extra water to the strict crop requirement to provide for leaching of salts. Of course, it is not strictly necessary that leaching water be provided with each irrigation application. It might be adequate in most circumstances if the leaching were carried out at the time of year when supplies are abundant. However, the system is not so flexible, nor is the watering system so efficient that we would dare only supply the strict amount necessary for evapotranspiration. Normally, the amount supplied to meet watering inefficiency is sufficient to provide adequate leaching. In some countries, when ground water is used in the dry season, the high wet season rainfall is usually adequate to provide the necessary soil leaching. Then, quite saline water can be used, providing the chosen crop will tolerate it. Such cases occur in Bangladesh and Thailand.

Drainage

In some circumstances the development of ground water has an additional benefit in that it lowers the water-table level and provides a degree of drainage not possible with any conventional drainage system. This benefit on its own can bring substantial returns in the form of increased yields over the drained area and in controlling the salinizing process that arises as a result of evaporation from a high water-table. However, it is really not possible for farmers themselves to operate a ground-water development scheme for critical water-table control. This can only be done by an operating authority, as far as this aspect is concerned, farmers generally tend to overpump and, if there are sufficient wells in the system, drainage is usually adequate.

Recharge

There are clear advantages in terms of water use efficiency when the underlying aquifer is directly recharged by surplus irrigation water draining from above. This is the case for projects in India, Pakistan, Bangladesh, Thailand and Indonesia in which we have been engaged. Normally, if there is no ground-water development, the water use efficiency is about 50 per cent, i.e., the amount of water actually used in evapotranspiration is 50 per cent of that diverted from the surface water source. If the water lost percolates to the aquifer and is pumped for re-use, then the water efficiency rises to 80 per cent.

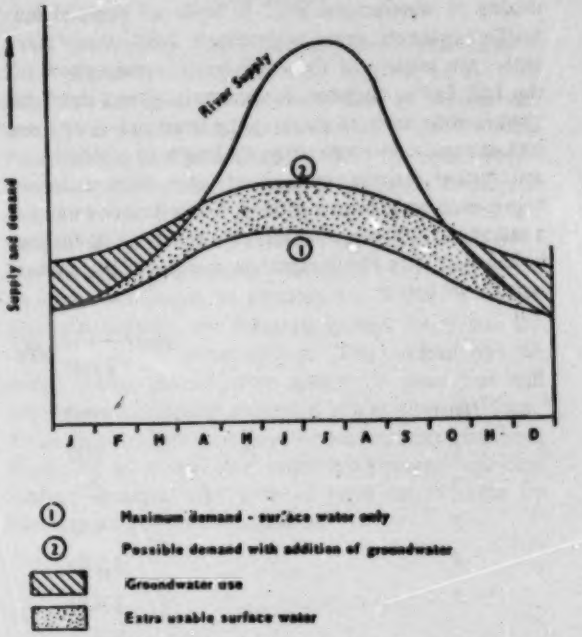
River Supply
Supply and demand
J F M A M J J A S O N D
① Maximum demand - surface water only
② Possible demand with addition of groundwater
Groundwater use
Extra usable surface water

Figure XI. Making better use of existing surface supplies

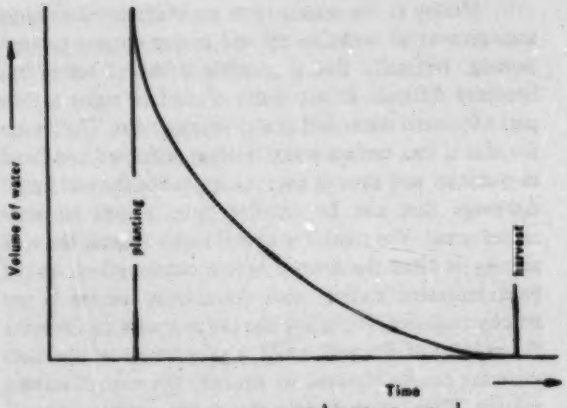

Figure XII. Concept of 'critical water'

Mixing

In the intial stages of a ground-water development project, there is often a marked degree of farmer resistance to overcome. Sometimes this has substance in that the ground water is of poorer quality than the traditional surface supply. In other cases, the objections are no less real but are based on the alleged value of silt in the surface water or perhaps its religious significance

1 This is in constrast to some areas in Java, where we are holding the debate at about the 300 per cent level.

or even, in the case of the Nile, its alleged virility power. Whatever the problem, it is often mitigated to some extent if the ground water can be mixed with surface water. Where there is a real problem of poor quality water, this can be done by discharging wells into the larger canals (where the effect will be small) or by mixing at watercourse level. If wells are pumped into smaller channels above watercourse level, then, inevitably, the salinity of the canal water increases towards the tail. Let us suppose, for example, that a canal discharges four units of water at the head and diverts one unit at regular intervals along its length to watercourses and further receives one unit of water from wells just below each watercourse offtake. If the surface water has a salinity of 200 parts per million (ppm) and 2,000 ppm well water, then the increase in salinity in the channel is as shown below:

Offtake	*Upstream salinity ppm*
Head	200
1	200
2	650
3	990
4	1,240
5	1,430

The mixed water in the channel rapidly becomes too saline for use, unless special practices are adopted.

Mixing at the watercourse generally involves some arrangement of weirs to try and ensure correct proportioning. Normally this is possible with 1:1 mixes but becomes difficult at two parts of surface water to one part of ground water and at any greater ratio. The reason for this is that surface water is often restricted and fixed in quantity and thus at high mixing ratios the maximum discharge that can be handled from a well becomes rather small. The matter is complicated because the well salinity is often not known before construction. As has been indicated earlier, such continuous mixing is not strictly required. Providing the crops grown can tolerate the salinity of the well water, a programme of alternate watering can be adopted to virtually any over-all mixing pattern. This latter scheme is a much more practicable proposition for the farmer, providing he can be made to understand the quality difference and the necessity for careful control.

Organization and management

Well operation and aquifer control

The management of a ground-water resource involves many elements common to any large national resource. It should not be freely exploited by individuals for their own benefit to the detriment of the common good. This principle is firmly recognized in most developing countries and discussed at great length. It is therefore all the more surprising that the debate results in no practical action and that often the ground water is over-exploited. The normal sequence of events is that a few farmers sink shallow wells or perhaps the government installs a project. Very soon, the obvious benefits are recognized and there is a well construction explosion, often assisted by the government through co-operatives, land mortgage banks or agricultural development agencies. After a few years, there is a serious drop in water levels and some wells go out of production. These might then be succeeded by deeper wells and so on until only the rich farmers can afford wells and the poor drop out of the race. This has actually happened in some projects in India.

Uncontrolled private development has its dangers, but there is no doubt that it is considerably quicker than public exploitation. In the Punjab Province of Pakistan some 9,000 wells have been installed by the public sector compared with some 120,000 by private farmers. However, it is true to say that it is probably the public development that sparked off the private sector.

There is also the matter of control. Farmers rightly place very high store on having control over their own water supply. They are then able to plant their cropping system with confidence. There is little doubt that they also operate more efficiently than a public authority in that they pump strictly according to their needs and they are able to arrange for repairs in the event of breakdown much more quickly. Sadly, control of such a vital resource leads them to exploit their neighbours, to whom they sell water at extortionate rates. This practice is certainly common in Pakistan and India.

Group-operated wells

In poorer areas or where holdings are traditionally small, the individual farmer can afford neither to construct a well nor to operate and maintain it. In these circumstances, it is usual to form a co-operative group. Sometimes, this arises naturally but, more usually, it is generated as a result of direct or indirect support by the government. Generally, a small group is a better proposition than a large one, although it is an economic fact that a large well is always cheaper than a small one in terms of cost of water delivered. Government support often takes the form of a loan to the farmer's group to construct a well, and this is repayable on very favourable terms; thereafter, the operation and maintenance is a matter for the group. This is the principle of a number of agricultural credit projects funded by the World Bank and the International Development Association in the Indian subcontinent.

In Bangladesh, thousands of wells are being sunk under the auspices of the Agricultural Development Corporation (ADC). The authority is funding the capital

development and handing over wells to farmer groups for operation, while ADC will carry out the maintenance. Charges, yet to be decided, will be made by ADC against the operating group.

Initial interest can sometimes be stimulated by pilot projects where the wells and channels are installed, initially operated and maintained by a public authority and water is supplied free on demand to the farmers. This is being done in Indonesia where it is hoped that, with the additional water, three crops a year will be raised instead of two. Special efforts are needed in such a case to convince the farmer of the benefits.

Maintenance

Frequently, the main trouble with ground-water schemes is the maintenance of pumps and motors. Mechanics with sufficient skill are not easy to find, nor is it easy to train an adequate number and to make sure that, when trained, they will remain in the village to carry out the required work. The private sector always has a demand for trained mechanics and a large purse to pay them. This problem rather militates against sophisticated modern and efficient machinery, except for the large public project. Recently, there has been a distinct tendency to go back to the heavy single cylinder diesel engine and to use centrifugal pumps wherever possible. These can be maintained locally, whereas the high speed diesel and deep well turbine pumps are much more difficult to maintain.

Conclusions

We conclude with a paradox. Farmers can operate wells efficiently but cannot even conceive of the problem of managing an aquifer. Public authorities can manage an aquifer but cannot operate wells efficiently for their best agricultural use. Striking the right balance is not easy and certainly varies from project to project. Clearly, in the future, all wells will have to be licensed and the number and discharge restricted to avoid over-exploiting the resource. If this can be enforced, there are clear advantages in allowing the farmer or farmer groups to operate and integrate ground water into the existing surface water system. This will always be easier where ground-water quality is good but will require a considerable extension effort when it is not. There is no doubt that government agencies have been successful in stimulating such development and that lending agencies have made a great contribution by their support and encouragement.

METHODS OF LEAK DETECTION: AN OVERVIEW*

In 1957, the American Water Works Association (AWWA) Committee on Revenue-Producing Water presented a report entitled "Revenue-producing versus unaccounted-for water,"[1] that was intended to aid the water utility industry in evaluating and improving conservation practices. The 11 members of the committee were managers, superintendents and engineers from various parts of the country; they represented investor-owned as well as publicly-owned utilities.

The committee agreed that the concept of metered ratio would be the first step in evaluating distribution system performance. (The metered ratio concept was included in the AWWA Annual Survey of Water Utility Operation.)[2] Metered ratio is the ratio of metered sales to metered delivery to the distribution system. Good performance is indicated by a ratio of 85 to 90 per cent, when the use of water is between 378 and 472 litres (100 and 125 gal) per capita per day. When industrial use causes a higher per capita use, the ratio may approach 100 per cent. The difference between the ratio and 100 per cent is unaccounted-for water.

Factors that affect the ratio are the age of the system and ground conditions, unavoidable leakage, pressures and the source of supply, the quality of materials and workmanship, use per capita per mile of main, the amount of industrial and commercial use, under-registration of domestic meters, and unauthorized use.

The Symposium on Waste Control

Any discussion of leak detection must refer to the Symposium on Waste Control, held at the University of Reading, United Kingdom, from 10 to 13 September 1974, sponsored by the Institution of Water Engineers. Much of the symposium was concerned with what is considered in the United States to be house waste and with water losses due to wasteful practice, rather than underground leak detection. In both the United Kingdom and the United States, the use of waste meters, defined as any type of flow meter, is considered an important aspect of leak detection and waste control. Such meters provide actual flow data on the existence and location of losses, including underground leaks.

Waste control study methods

Basically, a waste control study involves flow measurements, starting at the source of supply and arriving step by step at measurement of night-time rate of consumption in each individual section of the distribution grid. The first measurements check total daily delivery to the system from the source and the accuracy of the master meters. This step is followed by the measurement of daily consumption in the distribution system proper, divided into districts by appropriate valve operations. The average length of mains is about 29 km (18 miles) per district, but there can be wide fluctuations in individual cases (from 6.4 to 74 km of mains), depending on the situation.

Hourly rates of consumption in each district are analysed, taking into account the readings of large-consumer meter registrations, made simultaneously with the respective district measurements. From the data obtained, it is determined whether or not further investigations are needed to account for the measured consumption in the area.

In general, where minimum night rates of consumption are less than 50 per cent of the average daily consumption, there is little likelihood of water waste in the corresponding district. The probability of appreciable waste varies proportionately with this percentage. For example, when the district figure drops to 30 per cent or less, the likelihood of serious leakage is practically nil. Using these data, it is possible to reduce the amount of detailed investigation required to account for night rates of consumption. Normally, a number of districts will prove to have night rate-to-total consumption ratios so low that no further attention to these grids is required.

Such was the case in one city where 24 of the 68 districts had low minimum night-rate ratios.[3] The high rate was attributed to metered registration of large consumers. Accordingly, in these 24 areas it was determined that further investigation was unnecessary. These 24 districts covered 646 km (402 miles) of mains, or 35 per cent of the total 1,849 km (1,150 miles). Eliminating them from detailed study materially reduced the work and time required for the over-all study.

District measurements are valuable as guides for future control work. Comparison of new measurements

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1 *Journal American Water Works Association*, vol. 57, No. 12 (December 1957), p. 1587.

2 *Ibid.*, vol. 62, No. 6 (June 1970).

3 See B.E. Payne, "Shrinking non-water revenue", *Water and Wastes Engineering*, vol. 3, No. 8 (August 1966).

with previous figures provides a useful gauge of the probability of new or recurring water waste. Again, a simple measurement of the districts will often show that only a handful require detailed attention.

In this example, the detailed investigation of a district began with the subdivision of the area at night-time and the measurement of the water consumption rate in piece after piece of the distribution piping between existing serviceable values. The combined individual night rates of consumption should equal the amount of the measured night rate for the whole district. It was found that a large portion of most districts required no further study because the measured consumption rates were so low that they could be attributed to normal demand, plus small leaks and waste. As the subdivision process was being carried out, the large meters were read. Several of the higher rates to consumption were attributed to metered registration of large consumers.

The remaining areas in a district with unexplained high consumption rates were investigated in detail by visual and sounding methods. Sewers and culverts were inspected for water entering through joints or fissures; surface appearances of pavement, sidewalks and vacant lots were observed for depressions or wet spots; valves, hydrants and services were sounded for typical audible vibrations produced by water escaping from defects in the underground piping. To pick up leak noises, a sounding apparatus was used along the ground surface above the pipes at appurtenances. In some instances, steel bars were driven into the area around the leak before either sound or visual observations showed the actual location of the leak.

Waste meters

The 1974 Symposium on Waste Control concluded that "systematic waste control procedures involving the use of waste meters to locate and ultimately pinpoint leakage by sonic methods will always be more effective than procedures of routine sounding." The various types of waste meters can be described as rate of flow meters or differential meters. The presence and size of leaks can be efficiently investigated by waste meter flow monitoring equipment, at night as well as by day. Once the size and general location of the leak is known, it can be pinpointed by various types of sound intensifiers. Types of waste meters are listed below.

Deacon meter. In a Deacon meter, water passes downward through a diverging cone and flows around a central moving disc. The disc marks a moving chart driven by a clock. Since it is large and relatively costly, this meter is usually installed permanently.

Mobile meter. This was developed by the Water Research Association (WRA). The mobile meter is connected to a waste district by using fire hydrants and hydrant flows. This device used to be known in the United States as the hose and meter system and is still in use, although it is somewhat cumbersome.

Pitot tube. The Pitot tube is a differential pressure instrument that was developed in 1897 to measure the flow of water in pipes. The instrument can be easily installed through a one inch (2.54 cm) opening and is a less expensive and more practical device than the Deacon meter. It is a simple, portable, accurate instrument that does not require timed measurements. It is therefore the most convenient type of field instrument. The Pitot tube has been used extensively throughout North and South America, Europe and Asia.

Meter master. This is a device for converting the meter register action to rate of flow.

Leak detection techniques

In the view of WRA, the use of acoustic methods and equipment such as listening sticks, stethoscopes and electric amplifiers to pinpoint the location of leaks is not always successful. Therefore, WRA also developed the following alternative methods of leak detection.

Tracer gases. A water-soluble tracer gas such as nitrous oxide or helium, with special portable detection equipment, can be used to locate leaks. This is an expensive and time-consuming technique reserved for special conditions.

Correlation technique (LINDA). This is a technique for removing interference when acoustic methods of leak location are used. Signals on tape from up to 16 microphone pick-ups are recorded and processed on correlation equipment. This method was found to be accurate within 30-60 cm (1-2 feet) but proved too expensive and time-consuming for commercial application; thus, its use is limited to difficult and unusual situations. However, recent developments indicate substantial improvements in this method.

Pressure differential. A method described by R.M. Stenberg of Sweden as the pressure differential method uses a differential liquid manometer connected to taps along the pipe to measure friction gradients down to 2 in 1,000 and to establish a graph of the gradient lines on both sides of the leak.

Other methods for difficult situations have included the use of vegetable dyes or salt solution tracers, somewhat in the same manner as the nitrous oxide method. In 1978, the development of fluoride gaseous techniques was reported by WRA.

Commercial acoustical equipment. The basic acoustical leak detection equipment can be divided into mechanical and portable amplifiers. Examples of mechanical acoustical equipment are listening sticks, aquaphones and geophones. Portable amplifiers usually consist of a microphone pick-up feeding an amplifier

screening circuit; there are major differences in the design of the pick-up and the amplifier circuit.

Patent search

A recent patent search revealed that since 1935 16 patents have been registered for methods of locating leaks in buried pipelines. The basic information on these patents is presented in table 3. Seven of the devices are intended for use with oil or gas pipelines and four are used with industrial pipelines carrying valuable or toxic fluids. One is for sewer leaks, one is for rural water systems and one is used by plumbers for water service pipe leaks. Two of the patented acoustical methods used at present in water systems are listed in table 3.

Conclusion

There is a growing and active interest in leak detection and control. A successful programme should make use of proven methods, such as a combination of waste meter, district flow measurement and pinpointing procedures. The state of the art of leak detection is adequate for water utility programmes, but further application of known methods and techniques is needed.

Table 3. Leak detection divices patented, 1935-1976

Patent number, date, and inventor	*Abstract of disclosure or object*	*Application to buried pipelines*
2,008,934 July 1935 A.L. Smith	Sound pick-up and amplifier	Oil, gas and water
2,971,259 February 1961 H.F. Hahnau	Uses TV camera to locate infiltration or faults in sewer lines	Sewer leaks
3,045,116 July 1962 P.L. Gant (Continental Oil Co.)	Uses radioactive slugs to activate surrounding cover later detected by suitable recorder	Gas-carrying pipelines
3,170,152 February 1965 F.V. Long (Eastern Transm. Corp.)	Transducers inserted through ground cover to pipe, recording noise of leak at frequent intervals	Testing new pipelines with water or air
3,261,200 July 1966 F.V. Long (Eastern Transm. Corp.)	Improved method: uses relationship of sound signals to locate leak	Testing new pipes, oil, transmission mains
3,458,656 July 1969 H. Sewerin (Heath Son-I-Kit)	Uses highly sensitive microphone having maximum frequency range of 200 cycles and protective shielding	Water leaks in buried pipelines; presently in use
3,459,036 August 1969 P. Powell	Gas sampling probe (nitrous oxide) for detecting leaks in underground pipes; uses successive bar holes	New or long pipelines
3,600,674 August 1971 F.A. Roberts et al. (Chevron Research Co.)	Uses closed-loop radar system with a time-sharing transmissions line buried adjacent to pipeline	Oil in pipelines in permafrost zones
3,626,750 December 1971 C.A. Talmon (United States Conservation Corp.; Hydrotronics)	Detects leak frequency sound signals with microphone, amplifier, oscillograph mounted in a truck	Water, gas or fluids in buried pipelines; presently in use
3,711,689 January 1973 J.E. Park	Electronically monitors volume of liquid into and out of the system with control signals in the event of a leak; highly sophisticated	Oil line systems
3,721,898 March 1973 P. Dragoumis	For quick detection of industrial leaks involving toxic, radioactive or valuable liquids; the leak ruptures an electrical covering detected by a meter	Industrial use
3,771,350 November 1973 G. Romans	Pipeline leak detector which detects abrupt temperature changes caused by fluid escaping by infrared means; detector propelled through pipelines	Industrial or oil transmission mains
3,800,217 March 1974 D.J. Lowrance	A bare conductor is buried adjacent to a plastic pipe conducting liquid; when leak occurs, the electric circuit is closed	Rural water systems
3,848,458 November 1974 M Soya	Spheres or travelling body with sensors and counting means, a flow meter, a measuring pulse signal, and an alarm which is activated if count valve exceeds present value	Industry or high-value pipelines
3,851,521 December 1974 S.A. Ottenstein	Generates electric signals by negative pressure waves when break occurs	Industrial applications
3,930,556 January 1976 Kusuda et al.	Microphones set at large intervals in relatively long space detect sonic waves caused by leaks; a permanent installation	Long oil or fluid pipelines
Not patented; compressed air magazine	Inflatable rubber plug holds water pressure in specified sections of pipe	Service pipes; used by plumbers

NUMEROUS USES FOR EARTH REINFORCEMENT*

The use of earth reinforcement, the strengthening of a soil structure by materials installed to resist tension, has in recent years become widespread. The predominant method is reinforcement earth, a patented construction material developed in France and introduced in the United States in the late 1960s. Another patented European concept is the root pile, developed in Italy. Other earth reinforcement concepts include the use of nets, fabrics, earth anchors or paper grids. Some are modifications or variations of others; some are experimental; all have the same purpose: to increase the strength of a soil mass.

Initially, earth-reinforcement projects were designed with very high safety factors, but experience led to better understanding and more rational and economical designs. With this has come a broadening of application. As the late Dr. Kenneth Lee wrote in a symposium paper, "one of the attractive beauties of combining reinforcing elements with soil materials is the number and variety of possible design concepts and applications which come to mind."

Reinforced earth, a major emerging concept

In 1969, a reinforced earth retaining wall was built to correct a landslide on Route 39 in California. That was the first reinforced earth structure built in the United States; as of November 1978, 258 such structures had followed. Most have been retaining walls, but the product has proved versatile. Other applications include slide buttresses, foundation slabs, containment dikes, marine structures, coal storage slots and bridge abutments.

Reinforced earth is a construction material developed and patented by French architect/engineer Henri Vidal. It consists of a facing wall and compacted soil backfill reinforced with thin metallic strips. The strips, usually galvanized steel, absorb tensile stresses within the backfill by strip/soil skin friction. This holds the soil together as an integral mass, known as the reinforced earth volume.

The facing elements, usually interlocking concrete panels, are not structural members; they serve only to retain the soil between strips near the outer edge of the backfill and to make the structure more appealing to the eye. The panels are bolted to the reinforcing strips to keep the facing in place, and the entire structure (facing, backfill and reinforcement) behaves as a unit.

An example of the use of reinforced earth structures to overcome tricky foundation problems and save money is the 5 km (3 mile) extension of the four-lane Sprain Brook Parkway in Elmsford, New York. Reinforced earth bridge abutments and retaining structures being built at four locations there will save the New York Department of Transportation (NYDOT) about 50 per cent (more than $1 million) of the cost of conventional reinforced concrete retaining walls and abutments, claims the Reinforced Earth Company.

A retaining wall was needed to support a 12 m (40 ft) fill without increasing the overburden pressure on a nearby stone aqueduct used for the New York City water supply. The foundation soil was very soft. According to the Reinforced Earth Company, NYDOT designers chose a reinforced earth retaining structure because of its low bearing pressure, because it requires no footing extending beyond its face, and because it was the least costly retaining structure.

Other reinforced earth walls are being built to retain an embankment for a Sprain Brook Parkway ramp crossing the Saw Mill River floodplain. Because locally available fill is expensive, a conventional sloped embankment was too costly. Although the 15.5 m (52 ft) high structure is expected to settle as much as 25 cm (10 in), no damage to the wall is anticipated, because of its flexibility (facing panels can move slightly relative to one another). Two other walls, one 5.5 m (18 ft) and one 16 m (52 ft) high, are also being built at Sprain Brook.

No "Bump at the end of the bridge"

NYDOT also decided to use reinforced earth bridge abutments with wing walls. To allow the structures to carry the full bridge load, the density of reinforcing strips (number of strips per unit area of facing) was increased. This was especially important in the upper portion of the structure, where the load imposed by the bridge seat creates additional localized shear stress.

In this region, strips are longer and of greater cross-section than strips in lower portions (see figure XIII). Wing wall reinforcement strips are designed without consideration of the reinforcement provided by strips connected to the headwall.

Although most reinforced earth structures in the United States are retaining walls, there are now 48

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* By Michael J. Bartos, Jr., Assistant Editor, *Civil Engineering*. Reprinted, with permission, from the American Society of Civil Engineers (ASCE), *Civil Engineering*, vol. 49, No. 1 (January 1979), pp. 51-57.

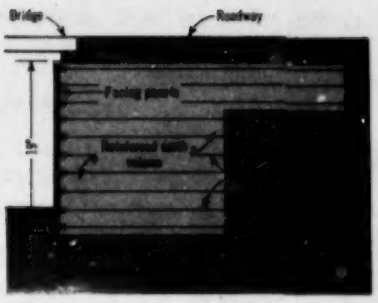

Figure XIII. Reinforced Earth structure consists of facing panels and compacted granular backfill reinforced with thin metallic strips. Strips, usually galvanized steel, absorb tensile stresses in backfill by skin friction, holding soil together as an integral mass known as Reinforced Earth volume.

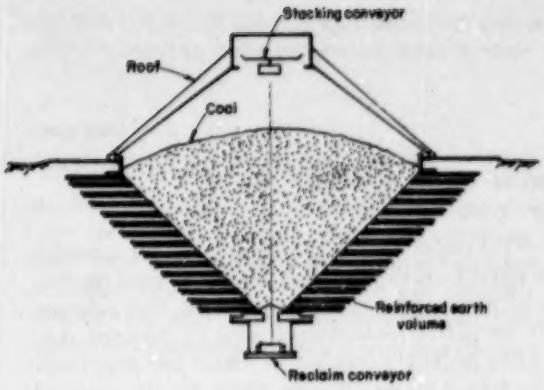

Figure XIV. Coal storage slot cross-section. Coal is loaded into slot using overhead conveyor and stored.

bridge abutments there. As Victor Elias, Reinforced Earth Company Vice President for Engineering, said: "Aside from economy, the principal technical advantage of reinforced earth abutments is their ability to withstand post-construction settlements without structural distress."[1] The bridge seat, which supports the end of the bridge superstructure, rests behind the facing on the reinforced earth volume. Because the abutment and seat settle as a unit with the approach fill, the "bump at the end of the bridge is eliminated" as Elias said.

Another important advantage of reinforced earth structures is speed of construction. At Sprain Brook Parkway, the contractor is constructing about 86 m^2 (930 ft^2) of wall per day, about average for reinforced earth construction. But along Route I-80 north near Glens Falls, Idaho, a contractor built two 1,100-m (3,500-ft) long walls (nearly 19,000 m^2 or 203,000 ft^2 of wall surface) at an average rate of 200 m^2 (2,000 ft^2) or 83 panels per day. On his best day, he placed 350 m^2 (3,800 ft^2), or 157 panels, a North American record. The two walls were finished in 100 working days.

First sloping-face structures

A recent development by the Reinforced Earth Company is the use of reinforced earth to construct coal storage slots. The application is different from others because it is the first use of a sloping reinforced earth structure; all previous structures have had vertical facing.

A coal slot is a long, V-shaped trench with sloping walls (see figure XIV). Coal is loaded into the slot using an overhead conveyor and stored. Because the walls slope at 50-60° from the horizontal, the coal, whose angle of repose is 38°, flows by gravity to the bottom of the slot, where it is removed by a conveyor beneath the slot. Coal slots, which are usually enclosed, are used at mines to store coal before shipment and at power plants to provide weather-protected storage.

In Gillette, Wyoming, reinforced earth was used to construct 3140 m^2 (33,800 ft^2) of sloping side walls at a Kerr-McGee Coal Company mine. Before that, the sloping end walls (an area of 1,530 m^2 or 16,500 ft^2) of a slot at Black Thunder mine, owned by the Thunder Basin Coal Company, had been the first such use.

Research and development were initiated on the sloping-face structure March 1977; the 1530 m^2 (16,500 ft^2) of end walls at Black Thunder were completed in mid-1977; and three more slots, including the one for Kerr-McGee, were to be finished by the end of 1978.

More reinforced earth structures

Notable reinforced earth structures illustrate the versatility of the reinforced earth concept, which the late Professor Kenneth Lee called "an emerging major concept in the field of civil engineering". In the same paper, a state-of-the-art report prepared for a symposium on earth reinforcement, Professor Lee spoke of the need for further study of friction between soil and reinforcing strips and the long-term durability of reinforcing materials.

Root piles reinforce soil without excavation

Another patented earth reinforcement technique is the "reticulated root pile" structure. Introduced in Europe by Fondedile some 30 years ago, a root pile is a small-diameter, cast-in-place, reinforced concrete pile, with high skin friction that binds it tightly to the soil. A "reticulated root pile" structure is a three-dimensional lattice of many root piles used to reinforce soil to the extent that the soil-root pile complex is considered to act as a unit. Stresses acting on the whole structure are assumed fully distributed within the ground and piles.

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1 Victor Elias, "Reinforced earth abutments, their design and performance" (preprint 3307), *Symposium on Earth Reinforcement* (New York, American Society of Civil Engineers, 1978).

Dr. Fernando Lizzi, Technical Director of Fondedeli, S.p.A., Naples, Italy, said, at the Symposium on Earth Reinforcement, that an important advantage of this ground-strengthening system was the construction of supporting and retaining structures with no excavation. "A structure can be built in any type soil," said Lizzi, "dense, loose, permeable, impermeable, rocky, semirocky, etc."[2]

Jeanne Pockel, manager of Fondedile's Boston office, added that: "the construction of the structure requires very little excavation, and excavation is done only at the surface to cast a preliminary capping beam into which the root piles are keyed. This means that no additional stresses are imposed on the unstable soil during construction."

Emphasizing the environmental and aesthetic qualities of a reticulated root pile structure, Pockel said that: "in many cases the entire structure, including the concrete capping beam, is underground; the original grade is retained or can be improved upon; and there is no offending structure visible. Even in those severe cases where extensive surface capping beams must be built, there is sufficient exposed soil to allow the planting of vegetation to conceal the artificial structures."

Lizzi reported three "typical patterns" for using root piles to correct landslides:

(a) For stiff soils and semi-rocky formations, the positions of several sliding surfaces are calculated. A "critical" surface is the one whose factor of safety with respect to sliding is 1.0; all soil above this surface is considered unstable. A root pile network is then constructed to: (i) encompass and reinforce the soil above the critical sliding surface and (ii) "nail" the strenthened soil structure to the underlying soil. The root piles are installed to the depth of a second (safe) potential sliding surface, so the safety factor of the structure is much greater than one.

(b) For rocky formations, the purpose is to form a strengthening network of sufficient thickness to convert the rock structure into a massive wall of fractured rock fastened together by root piles. No surface capping is necessary, but wire mesh reinforced by cables protects against small falling rock pieces. Root piles for this use differ from rock bolts because there are usually many more per unit area, so the stress in each is relatively low.

(c) For loose soil, it is better to create an underground "gravity" wall of root piles, dividing the landslide into two parts to protect the uphill portion of the slide. The design can be similar to that for stiff or semi-rocky soils, or can be based on the assumption that the lower portion is free to slide, leaving a cantilever wall.

Such an underground "reticulated root pile" retaining wall was used to prevent sliding of a concrete bridge abutment on expansive clay. The bridge, a four-lane structure carrying Route I-55 over a rail line near Jackson, Mississippi, is a five-span structure supported by six-column concrete bents. One bridge abutment was found to be sliding towards the railroad tracks; in fact, some abutment piles were exposed and the Mississippi Department of Transportation had sheared one from the wing wall to keep it from over-turning.

To correct the situation, Fondedile installed a maze of root piles to reinforce the embankment supporting the abutment and underpinned the bridge using root piles drilled through the column-bent foundations (see figure XV). Those root piles that stabilize the embankment were installed through sleeves in a reinforced concrete capping beam, which unifies the structure and distributes stresses throughout the pile system.

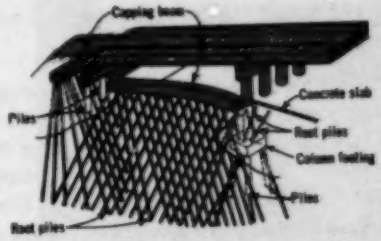

Figure XV. Underground "reticulated Root Pile" gravity retaining wall halted sliding of reinforced concrete bridge abutment on expansive clay near Jackson, Mississippi. Maze of Root Piles reinforced embankment supporting abutment and underpinned column-bent foundations. System, which stabilized landslide and supported bridge while new embankment was constructed, was installed gradually, without disturbing clay.

The root pile system, which not only stabilized the landslide but also supported the bridge while the embankment was reconstructed, was installed gradually, without excavating the expansive clay.

Study reinforcement of soil beneath footings and embankments

King's College (London) engineers R.H. Bassett and N.C. Last have extended the concept of earth reinforcement to the problem of increasing the bearing capacity of soil. They cited two methods for reinforcing the soil beneath an embankment or foundation footing.[3]

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2 Fernando Lizzi, "Reticulated root piles to correct landslides" (preprint 3370), *Symposium on Earth Reinforcement* (New York, American Society of Civil Engineers, 1978).

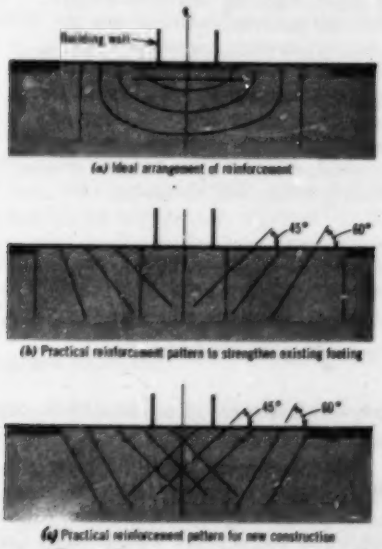
3 R.H. Bassett and N.C. Last, "Reinforcing earth below footing and embankments" (preprint 3314), *Symposium on Earth Reinforcement* (New York, American Society of Civil Engineers, 1978).

The first method is to place horizontal reinforcement in the base of an embankment section to prevent lateral spread. (The Pennsylvania Department of Transportation used a similar principle when they constructed a reinforced earth foundation slab to support a highway embankment on cavernous limestone.)[4] The second method would be to reinforce the foundation soil itself by inserting reinforcing tendons. It is this second method the authors described in their paper.

> "A robust reinforcement and placement method would be required. Small-diameter (10 to 15 cm or 4 to 6 in.) pressure-grouted ground anchors would suit the requirement almost perfectly. The bar or cable component of the anchor would provide the stiff reinforcement material. The drilling and pressure-grouting (in clays, underreaming) would provide almost ideal bond, and anchors are conventionally drilled at any inclination from 25° below horizontal to vertical."

They added that friction piles could be considered as an alternative reinforcement.

The ideal reinforcement pattern, oriented to resist tension, would be to lay reinforcement horizontally below the footing and progressively more vertical at some distance away on either side. Because this pattern is not practical for *in situ* construction, however, Bassett and Last used the two simplified patterns shown in figure XVI in their model tests. Using thin (1.0-mm diameter or 0.04-in.) steel rods and drinking straws (4.0-mm or 0.16-in. diameter) as reinforcement, tests showed:



(a) Ideal arrangement of reinforcement

(b) Practical reinforcement pattern to strengthen existing footing

(c) Practical reinforcement pattern for new construction

Figure XVI. English engineers have tested method of reinforcing earth beneath foundation walls and embankments. Ideal reinforcement pattern (a), designed to resist tension, was impractical to install, so they tested two more practical patterns (b & c). Using drinking straws and thin steel rods for reinforcement, they built scale models and tested them. Conclusions:
1) Straws are better reinforcement.
2) Reinforcement nearly doubled bearing capacity of sand. They say reinforcement should be 'robust', suggest earth anchors would be suitable.

(a) The straws (less stiff but four times the diameter of the steel roads) were the more effective reinforcement. They concluded that "the reinforcement should be of sufficiently large diameter or closely spaced enough for the whole mass to be influenced."

(b) "The reinforcement displaces the distortion mechanism to a greater depth and hence increases the bearing capacity." The reinforcement nearly doubled the bearing capacity and stiffness of the sandy soil they tested.

On the basis of their investigation, Bassett and Last considered the data presented justified further examination of soil reinforcement to improve or alter the response of soils in many engineering situations. They also believed there was "sufficient justification for ground anchors to be considered as a technique for improving the performance of a real footing or embankment foundation on both non-cohesive and cohesive soils."

Experiment with sand-filled paper grids

To develop an earth reinforcement concept for use in low-cost or expedient highway construction, Rea and Mitchell have experimented in the laboratory with a system of interconnected paper-walled grids about 5 cm (2 in.) square and 15 cm (6 in.) high filled with sand. They summarized the reinforcement mechanism of the paper grids (they said plastic, fabric and metal grids were equally suitable) as follows:

(a) The sand is confined and restricted against large lateral displacement until the tensile strength of the reinforcement is exceeded;

(b) Tension in the reinforcement gives a corresponding compression in the sand contained within a cell, thus giving increased strength and stiffness to the sand in regions beyond the edges of the loaded area;

(c) The development of continuous shear planes through the reinforced layer is inhibited.[5]

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4 See *Civil Engineering*, vol. 45, No. 7 (July 1975), pp. 54-56.

5 Charles Rea and James K. Mitchell, "Sand reinforcement using paper grid cells" (preprint 3130), *Symposium on Earth Reinforcement* (New York, American Society of Civil Engineers, 1978).

Triple bearing capacity

They tested 91-cm (36-in.) square boxes containing sand-filled paper grids resting on foundations of different stiffness. They applied a circular load and measured vertical deflections.

Their paper grids increased the bearing capacity of sand under static loading by as much as 300 per cent. While unreinforced dry sand has essentially no resistance to repeated load, reinforcement greatly increased resistance.

Because repeated loading caused sand to be displaced from the cells, Rea and Mitchell suggested that "resistance to repeated load would be enhanced by provision of some restraint to particle movement at the surface. A bituminous surface treatment might be suitable for this purpose."

They envisioned simple rules for construction:

(a) Grade and compact subgrade;

(b) Stretch paper honeycomb over subgrade grade surface and fill with sand;

(c) Compact sand, preferably by vibration;

(d) Apply surface treatment.

Fabrics and nets

Experiment with fabric reinforcement in Sweden

Professor Bengt Broms of the Swedish Royal Institute of Technology reported the testing of polyester fabric to reinforce soil behind retaining walls.[6] The fabric, either tied to L-shaped concrete wall elements or placed loose in the soil (see figure XVII) is placed in horizontal layers and reduces the lateral pressures on the wall. The total lateral force at the back face of the wall elements is resisted by the fabric reinforcement and by the friction along the base of the wall.

The spacing of the fabric layers is governed primarily by the long-term creep strength of the fabric and by the total lateral earth pressure acting on the retaining structure. The long-term creep strength of the fabric is still an open question, because experience from long-term tests is lacking. Therefore the allowable stress of the fabric with respect to permanent (dead) loads should be kept relatively low until sufficient information about the long-term fabric strength becomes available.

He added that the required anchor length of the fabric would be relatively short, because the total width of the fabric effectively transfers tensile force in the fabric to the surrounding soil.

The fill behind the retaining wall should be carefully drained so that the pore water pressure in the soil can be neglected. The fill should preferably be sand or gravel with a high permeability, and the percentage of silt and clay size particles (0.06 mm) preferably less than 10 per cent.

Japanese reinforce railway embankments with nets

Japanese National Railraod (JNR) engineers have investigated the use of synthetic resin nets to increase the ability of railway embankments to resist damage caused by earthquakes, volcanoes and typhoons. JNR soils engineers Iwasaki and Watanabe reported that about 50 per cent of major JNR track damage since 1878 "has occurred on the slopes of earth structures."[7]

Figure XVII. Swedish professor reports that synthetic fabric, either tied to L-shaped retaining wall elements or placed loose in soil, reduces lateral earth pressure on wall. Anchor length required for fabric is low, but he cautions that stress should be kept low until more is known about long-term creep strength of fabric.

Figure XVIII. To strengthen Japanese National Railroad embankments against earthquakes, volcanoes and typhoons, research committee recommended use of control nets at each lift. Control nets are 6 ft wide along embankment edges. Effects are: 1) Thickness of each lift of fill after compaction can be observed. 2) Compaction equipment can work at edge of lift. 3) Embankment is reinforced against earthquake. 4) Failure by slope erosion can be prevented.

6 Bengt B. Broms, "Design of fabric reinforced retaining structures" (preprint 3128), *Symposium on Earth Reinforcement* (New York, American Society of Civil Engineers, 1978).

7 Komei Iwasaki and Susumu Watanabe, "Reinforcement of railway embankments in Japan" (preprint 3181), *Symposium on Earth Reinforcement* (New York, American Society of Civil Engineers, 1978).

In May 1965, the Morioka Construction Bureau of Japan devised a method for reinforcing earth embankments using nets. After testing the resistance of net-reinforced embankments to rainfall from November 1966 to May 1967, the first reinforced embankment was built in March 1968.

"At each lift of fill in the course of construction of railway embankments," write Iwasaki and Watanabe, "nets 2 m (6 ft) wide should be placed along the shoulder of the fill (see figure XVIII). These nets may be called 'fill control' nets. The effect of these fill control nets is as follows:

"(1) The thickness of each lift of fill after compaction can be observed.

"(2) The whole embankment can be compacted uniformly and sufficiently by operating earth work equipment at the shoulder of the fill.

"(3) The embankment is structurally reinforced against earthquakes.

"(4) The failure due to erosion of slopes can be prevented."

Iwasaki and Watanabe said that a research committee has been working to establish a new standard for railway earth structures. Their objective is to develop earth embankments that have high strength and require little maintenance. One recommendation: "Concerning fill work, control nets must be laid at each lift."

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The preceding article was based on papers presented at a mini-symposium on earth reinforcement held in April 1978 at the ASCE national convention. Symposium proceedings, including all technical papers, the keynote address by Henri Vidal and panel discussions, are now available from ASCE. Entitled *Symposium on Earth Reinforcement*, the two-volume, 912-page, proceedings can be ordered from the American Society of Civil Engineers, 345 East 47th St., New York, NY 10017, United States of America. Copies of most single papers (Preprints) cited in the article can be ordered using the coupon on page 165 on the June 1978 issue of *Civil Engineering* or by writing to the above address. Preprints 3307 and 3370, which were presented at the October 1978 ASCE convention, can be ordered by using the coupon on page 87 of the December 1978 issue of *Civil Engineering* or by writing to the Society.

RESEARCH AND DEVELOPMENT

Programming a pocket calculator for solving multiple well, variable pumping rate problems*

Introduction

The mathematics associated with many groundwater analyses are often of a complexity which requires considerable time to solve by hand, and yet still do not justify the use of a computer. Straightforward nonequilibrium problems, composed of combinations of discharge/recharge wells and image wells, are examples. These are often most economically approached in the classic manner using a nonequilibrium equation plus additive drawdown theory.

Until very recently, this approach involved much calculator and paper work with frequent listings. Now, however, several moderately priced programmable pocket calculators are able to accept programmes for solving rapidly and accurately the Theis convergent series formula. With the programme stored in the calculator, the proper value of $W_{(u)}$ can be quickly determined by keying in u. Obviously, this is a timesaver during routine calculations and is valuable in the field or anywhere the well function listings are not readily at hand.

However, this new ability has a much greater significance. By freeing the Theis equation from the reference tables, it is now possible to use this versatile equation as a subroutine to other programmes designed to solve a host of complex nonequilibrium problems on a simple input-output basis.

Basic Theis convergent series programme

The Theis well formula is expressed in textbooks as follows:

$$W_{(u)} = -0.5772 - \ln u + \frac{u^1}{1 \cdot 1!} - \frac{u^2}{2 \cdot 2!} + \frac{u^3}{3 \cdot 3!} - \frac{u^4}{4 \cdot 4!}$$

To solve the formula the value of each term of the series must be calculated until the difference between the nth term and the (nth + 1) term is insignificant. This repetitive calculation can be accomplished by a calculator through a programme loop which makes the required modifications to each new term computed. The loop calculation is repeated until term differences decrease to an insignificant value which is preselected and placed in calculator storage by the operator.

Figure XIX shows a general flow chart for a basic Theis formula programme solving $W_{(u)}$ for input values of U. In the chart, "R" represents calculator storage register. The equal sign is best interpreted as meaning "place into storage." For example, $R_2 = R_2 + 1$ means "place into storage register R_2 the number obtained by adding 1 to the number presently in R_2".

For this programme, a value of 10^{-10} works well as the term difference limit to stop the series loop calculations. This limit permits the calculation of accurate $W_{(u)}$ values up to u = 10, while at the same time keeping the series to five or less calculated terms for values of u under about u = 0.01. For u = 0.1, 7 terms are calculated, for u = 1, 13 terms, for u = 5, 26 terms, and for u = 10, 40 terms.

As it takes roughly 2 seconds for each trip through the programme loop, a higher term difference limit might be desirable when working with many high u values, in order to trade off accuracy for speed.

It should be noted that 0.577215664 is used in the programme rather than the abbreviated 0.5772 found in most textbook expressions of the Theis formula. It is necessary to expand the constant in order to maintain accuracy in the highest u ranges (u > 1).

Expanding the basic programme

Figure XX illustrates a programme incorporating a Theis formula solution and designed to solve time-distance-drawdown problems from multiple well and/or variable discharge input. A variable discharge well is handled by creating an image well for each change in discharge rate and superimposing over the real well. For example, a well which begins pumping at 2,000 gallons per minute (gpm) for 3 days, then slows to 500 gpm for 4 days, and finally increases to 1,500 gpm for the final 2 days of pumping, is modelled as a 2,000 gpm well pumping for 9 days, plus a -1,500 gpm (500 gpm - 2,000 gpm) image well pumping for 6 days, plus a 1,000 gpm (1,500 gpm - 500 gpm) image well pumping for 2 days.

The following values must be placed into the appropriate storage registers prior to using the programme.

Total elapsed time (t_e), which is the time in days from the beginning of pumping of the first well to the

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* By Larry W. Picking, Senior Geologist, Stone and Webster Engineering Corporation, Reprinted from *Ground Water*, vol. 17, No. 2 (March-April 1979), pp. 205-207.

time at which drawdown is to be computed; coefficient of storage (S); transmissivity (T) in gallons per day per foot; the series converging factor (recommend 10^{-10}); and the constant, -0.577215664. Also, the register that stores the tallied drawdown values (s_f) and the register that stores interim Q values (Q_w) must both be preset to zero. The distance (r) in feet between each well and the point at which drawdown is to be computed must be entered into storage just prior to entering the time-pumping data for that well.

Table 4 presents the programme listing for the Hewlett-Packard HP29C calculator. An example of a typical problem is as follows:

A 1-ft diameter well is fully screened in an artesian aquifer of storage = 0.001 and transmissivity = 46,000 gpd/ft. Four hundred feet west of the well is a river which acts as a recharge boundary. The well is to be pumped according to the following schedule:

Begin pumping at 2,000 gpm.

After 2.4 days, reduce pumping to 800 gpm.

After 4.1 days, increase pumping to 1,500 gpm.

Cease pumping after 6.6 days.

What is the drawdown in the well:

3.3 days after pumping began?

At the instant pumping is terminated?

0.2 days after pumping is terminated?

Assume 100 per cent well efficiency.

Using the programme in figure XX and Table 4, this problem can be solved as follows:

Step 1: Load programme. Pleace constants into appropriate registers.

Set $s_f = 0$

Step 2: Set $r = 0.5$, $t_e = 3.3$, $0_w = 0$. Key in the time-discharge data for real well up to the 3.3 days. For the HP29C, this is done as follows:

1. 0
2. ENTER
3. 2,000
4. GSBO
5. 2.4
6. ENTER
7. 800
8. GSBO

Read : 41.79 (ft) which is drawdown at t = 3.3 days absent image well effects.

Step 3: Reset $r = 800$ (distance from real well to recharge image well) and $Q_w = 0$. Key in time discharge data again, only make pumping rates negative to indicate recharge.

Read: 29.45 (ft), which is the drawdown in the well after 3.3 days of pumping according to the stated schedule.

Step 4: Reset $Q_w = 0$, $s_f = 0$. Set $t_e = 6.6$, $r = 0.5$. Key in full pumping schedule.

Read: 73.33 (ft).

Step 5: Reset $Q_w = 0$. Set $r = 800$. Key in full pumping schedule, making pumping rates negative for the image well.

Read: 55.11 (ft), which is the drawdown in the well the instant pumping ceases.

Step 6: Reset $Q_w = 0$, $s_f = 0$; Set $t_e = 6.8$ (6.6 days + 0.2 days), $r = 0.5$. Key in full pumping schedule. It will now be necessary to indicate the end of pumping by keying in 0 pumping rate at 6.6 days, since we are now interested in residual drawdown at a time after pumping ceases. For example, for the HP29C, the schedule will now be input by keying the following:

1. 0	9. 4.1
2. ENTER	10. ENTER
3. 2,000	11. 1,500
4. GSBO	12. GSBO
5. 2.4	13. 6.6
6. ENTER	14. ENTER
7. 800	15. 0
8. GSBO	16. GSBO

Read: 12.87 (ft).

Step 7: Reset $Q_w = 0$. Set $r = 800$. Key in previous schedule, making pumping rates negative for the image well.

Read: 0.45 (ft), which is the residual drawdown remaining 0.2 days after termination of pumping.

Once familiar with the programme, many useful modifications will become apparent. For example, it would be simple to add an option that would internally change signs for recharge image wells when operator selected, so negative pumping rates would not have to be keyed in. Or, if enough storage in available, the entire pumping schedule could be placed into storage and automatically called up by the programme as needed.

Table 4. Multiple well, variable pumping rate programme for Hewlett Packard HP29C calculator (see also figure XX)

1. LBLO	21. RCL2	41. RCL.2	61. 1
2. ENTER	22. X^2	42. +	62. 1
3. ENTER	23. x	43. RCL.1	63. 4
4. RCL4	24. RCL5	44. +	64. .
5. –	25. x	45. STO+.3	65. 6
6. STO9	26. STOO	46. RCL.3	66. x
7. R↓	27. 1	47. RCL.4	67. RCL9
8. STO4	28. STO.1	48. –	68. x
9. R↓	29. 0	49. RCL.3	69. RCL6
10. RCL1	30. STO.2	50. STO.4	70. +
11. –	31. STO.3	51. +	71. STO+3
12. CHS	32. LBL1	52. RCL8	72. RCL3
13. RCL6	33. 1	53. X≤Y	73. RTN
14. x	34. STO+.2	54. GTO1	
15. 1/X	35. RCL.2	55. RCL7	t_e – STO1
16. 1	36. STOx.1	56. RCLO	r – STO2
17. .	37. RCLO	57. 1n	s_f – STO3
18. 8	38. CHS	58. –	Q_w – STO4
19. 7	39. RCL.2	59. RCL.3	S – STO5
20. x	40. Y^x	60. –	T – STO6
			–.577215664 – STO7
			10^{-10} – STO8

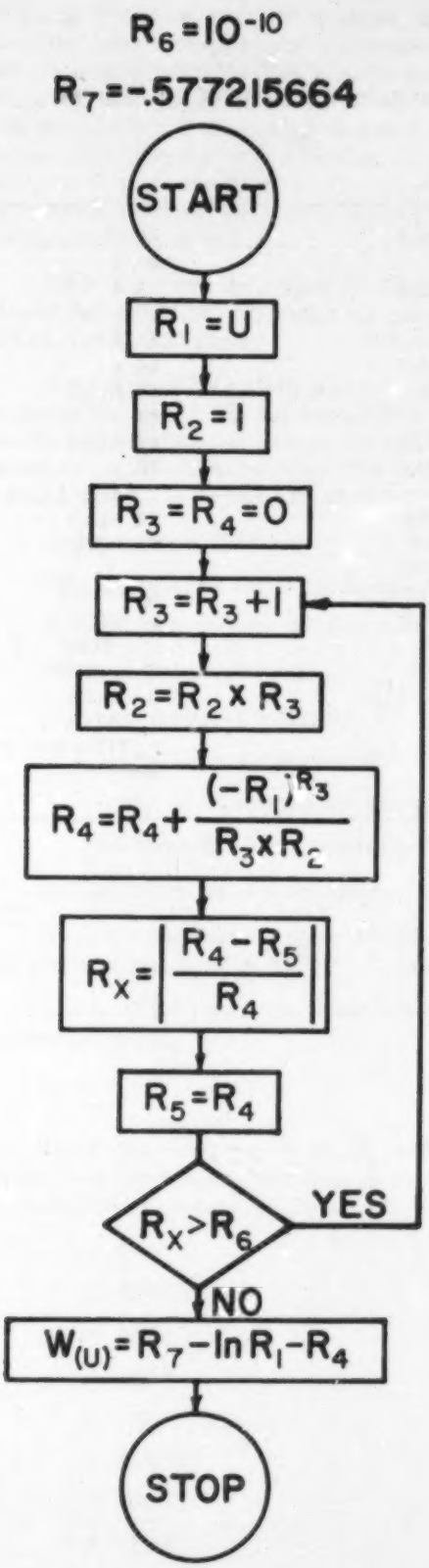

Figure XIX. Basic Theis formula programme

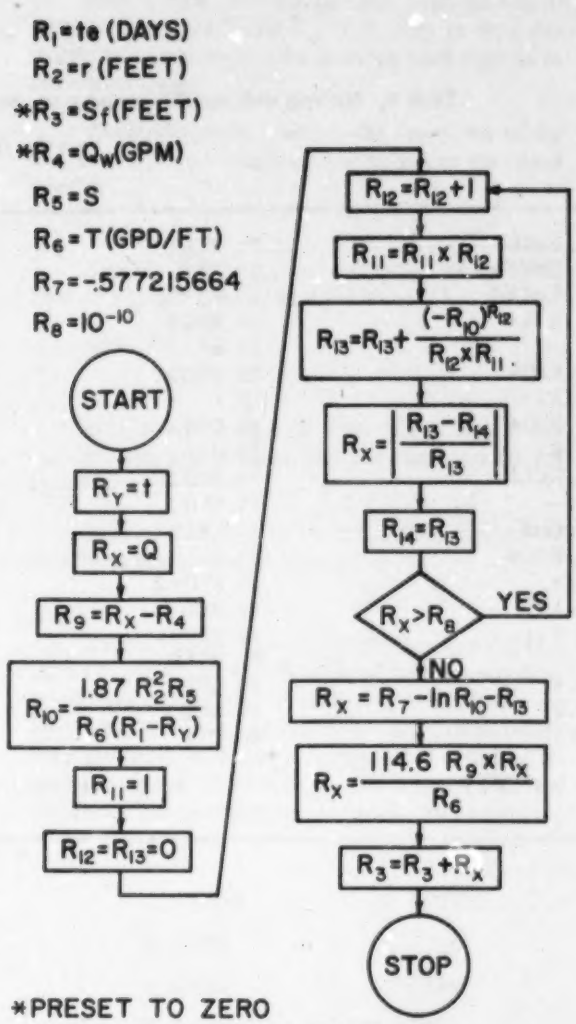
R_1 = te (DAYS)
R_2 = r (FEET)
*$R_3 = S_f$ (FEET)
*$R_4 = Q_w$ (GPM)
R_5 = S
R_6 = T (GPD/FT)
$R_7 = -.577215664$
$R_8 = 10^{-10}$
START
$R_Y = t$
$R_X = Q$
$R_9 = R_X - R_4$
$R_{10} = \frac{1.87\, R_2^2 R_5}{R_6 (R_1 - R_Y)}$
$R_{11} = 1$
$R_{12} = R_{13} = 0$
$R_{12} = R_{12} + 1$
$R_{11} = R_{11} \times R_{12}$
$R_{13} = R_{13} + \frac{(-R_{10})^{R_{12}}}{R_{12} \times R_{11}}$
$R_X = \left| \frac{R_{13} - R_{14}}{R_{13}} \right|$
$R_{14} = R_{13}$
$R_X > R_8$
YES
NO
$R_X = R_7 - \ln R_{10} - R_{13}$
$R_X = \frac{114.6\, R_9 \times R_X}{R_6}$
$R_3 = R_3 + R_X$
STOP
*PRESET TO ZERO
R_X & R_Y ARE STACK REGISTERS

Figure XX. Multiple well, variable pumping programme

Conclusions

Personal scientific calculators have advanced to a point where programmes for solving complex hydrological problems can be accepted. They fill a gap between hand calculation and centralized computers, and the advantages of low cost, portability and personal access are obvious. Development and publication of practical calculator programmes designed to solve routine problems encountered in applied geo-hydrology should be encouraged.

Simple solar well pumps in prototype stage[1]

Howard P. Stubbs of the Solar Pump Corporation has developed an improved solar-powered well pump which integrates a solar collector with components such as a freon boiler, engine, controls and condenser into an 11 sq m. compact unit. This unit can deliver 15,000 l/day against a 12-m head if operated at 38° north or south latitude. The pump automatically begins to work three hours after sunrise and continues at a deliberate pace until three hours before sunset; on partly cloudly days it stops and starts. Currently, prototype units are being tested in India and England by World Bank consultants. (Originally published in *Solar Energy Digest*, November 1979).

International ground-water news[1]

India – In a measure aimed at increasing the country's use of irrigation, officials intend to allow PVC resin, utilized in the production of irrigation pipes, to enter the country duty-free. Currently only 29 per cent of sown areas are irrigated and less than 25 per cent of the ground water is used.

Philippines – Since the beginning of this year, the Tiwi geo-thermal plant, powered by the volcano Mount Mayon, has produced more electricity than the Bicol region can use. Currently, the plant produces 55 megawatts and by 1981, when the operation's final phase is complete, the plant is expected to produce 220 megawatts. Because Mount Mayon is so active, engineers need to drill only a few hundred metres beneath the surface to reach hot magma.

Scientific divining rod[2]

A scientific divining rod for locating underground water resources is under development at Macquarie University, Sydney, Australia. The device measures the short high-frequency electromagnetic waves emitted by lightning. This electrical energy stored in the earth's surface is collected and then interpreted by the divining rod. Electrical "conductivity rises considerably where there is water," said geophysicist Keeva Vozoff, head of the project. "We will be able to locate water nearest the surface and determine where it lies in large volumes for towns and factories. The method is based on solid physics instead of the ancient divining rod method." The technique is an extension of work on deeper targets such as those in petroleum exploration.

Communications satellite-supported water information service[3]

A pilot programme for a communications satellite-supported water information service will be set up by COMSAT General Corporation under a contract awarded by the United States Geological Survey (USGS). The $2.2 million programme will test the feasibility of establishing a full-scale system to collect hydrologic data such as stream stages and water quality from USGS water monitoring stations and transmit the data to receiving stations by commercial satellites.

Hydrologic data collected by sensors at an initial 75 data collection sites in seven states will be transmitted by solar-power-celled, battery-operated radios to commercial communication satellites in stationary orbit 35,680 km above the equator. Data will be relayed from the satellite via an earth receiving station to a processing facility operated by Environmental Research and Technology, Inc. at Concord, Massachusetts, for identification, screening and processing. Processed data will be transmitted via telephone lines to USGS computers at the National Center in Reston, Virginia, which, within minutes, will make available hydrologic data collected at the 75 sites.

When the two-year pilot programme is completed, an analytical study will determine the feasibility of integrating virtually all of the 9,000 continuous monitoring hydrologic data collection stations of the USGS into the satellite data retrieval system. The system would replace the current method of manually retrieving data tapes from monitoring stations every four to six weeks.

Bureau of Reclamation: change of name[3]

The Bureau of Reclamation has changed its name to the Water and Power Resources Service to reflect changes in emphasis that have been made in the function of the agency. "National needs and concerns now call for greater efficiency in the operation of existing structures and their integration in new programmes for renewable resources and alternative energy," said Secretary of the Interior Cecil D. Andrus. The Bureau of Reclamation's initial purpose of reclaiming arid western lands established on 26 May 1926 as amendments to the Reclamation Act of 1902 has expanded to a much broader responsibility for water and power resource management. "The Water and Power Resources Service is very concerned with its role in the total environment and hopes to enhance the public's understanding of, and participation in, the management of water and renewable energy resources," said the commission's

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1 Reprinted from *The Ground Water Newsletter*, vol. 8, No. 22 (30 November 1979).

2 Reprinted from *Water Newsletter*, vol. 21, No. 20 (31 October 1979).

3 Reprinted from *Water Newsletter*, vol. 21, No. 22 (30 November 1979).

head R. Keith Higginson. Although water supply in early reclamation projects was primarily used for irrigation, today project water augments domestic and industrial supplies and over-all water quality is improved. To meet expanding needs in the future, increased irrigation efficiency, water conservation and the reclamation of wastewater will be necessary.

The Water and Power Resources Service is responsible for 333 reservoirs among the water and power projects. Some or all of the water is used from these by more than 16 million people, or 30 per cent of the population of the 17 western states. Water from the projects is also used by more than 146,000 farms, totalling about 3.6 million hectares of irrigated lands. Fifty hydroelectric plants in the Service generate more than 40 billion kilowatt-hours of energy each year. The projects are all initiated by locally autonomous water districts and communities, which contract to repay a portion of the capital costs.

For the future, the Service plans to update existing powerplants with additional turbine-generators and the rewinding of old genrators. "As to energy," Commissioner Higginson said, "hydroelectric power is solar. Unlike other forms of solar energy, hydroelectric energy can be easily and economically stored in reservoirs to be released on a moment's notice to firm up more conventional electrical sources." Hydroelectric power makes the use of wind turbines economically feasible and "will help to make possible other sources of utility-sized solar power by filling in lapses in generation from passing clouds and the coming of nightfall." New emphasis, the Commissioner said, will also be on installing power plants at the thousands of existing lowhead structures across the United States.

SELECTIVE INFORMATION SECTION*

* Most of the abstracts reproduced below are from the Selected Water Resources Abstracts of the Water Resources Scientific Information Center, Office of Water Research and Technology, United States Department of the Interior, for which acknowledgement is hereby gratefully recorded.

Subject	*Source*	*Description*
Conservation in domestic and municipal use	A.P. Brigham, "A public education campaign to conserve water", *Journal American Water Works Association*, vol. 68, No. 12 (December 1976), pp. 665-668.	A public water conservation compaign begun in 1970 by the Washington Suburban Sanitary Commission (WSSC) substantially reduced water use in the bi-county Maryland area adjacent to Washington, DC. Between autumn 1971 and June 1973 water use dropped from 101.6 gallons *per capita* per day (gpcd) to 100.2 gpcd, a net minimum saving of 1.7 million gallons per day (mgd). Following a bottle kit project in summer and autumn 1973, in which plastic quart bottles were used to displace toilet flush water and dye was used for making leak checks, water consumption dropped further to 97.0 gpcd. This was a 4.42 per cent reduction from the minimum projected average daily consumption of 122.2 mgd without the conservation programme. In addition, sewage flows from the WSSC service area in late 1973 and 1974 dropped well below the levels of 1972-1973; flow decreased from 128.5 mgd in September 1972 to 120.6 mgd in September 1973 and 114.44 mgd in August 1974. After preliminary flier and spot announcements in 1970, a water-saving idea contest launched late in 1971 resulted in publication and distribution of handbooks on water conservation to some 370,000 customer services and apartment dwellers. Subsequent projects from 1971 to 1973 were water-saving workshops and slide presentations, a water-saving fixture list, public service announcements, an appliance testing programme and plumbing code changes.
Conservation in domestic and municipal use	W.E. Sharpe and C.A. Cole, "The impact of water saving water closets on building drains and sewers", *Plumbing Engineer*, vol. 5, No. 6 (November-December 1977) pp. 20-21, 60	The effect of the use of water-saving toilets on drainage and sewage systems is evaluated. Water closets with discharges ranging from 0.25 to 5.25 gallons per flush were compared in terms of solid sewage velocity, sewer pipe diameter, sewer pipe slope and depth of flow. The average water-saving water closet discharges 3.5 gallons per flush. Necessary velocities for the transport of solid sewage were calculated as 1.5-2.0 ft/sec. The velocity for a water-saving toilet with a discharge of 3.50 gallons per flush was discovered to be 1.88 ft/sec. This velocity was considered adequate for sewage transport. The depth of flow was considered a potential problem in the use of water closets with a discharge of less than two gallons per flush. Large-scale installation of low-flow water closets in a Pennsylvania resort did not present adverse effects to the sewage system, although detailed data were not available.
Conservation in agriculture	J.K. Jain, "Policy of pricing irrigation water", International Commission on Irrigation and Drainage (ICID) *Bulletin*, vol. 26, No. 1 (January 1977) pp. 41-49	Based on analysis of irrigation water pricing issues and theory, a guideline is suggested for formulating governmental pricing policy and its application is described for India. Major aspects are: (1) subsidies up to 50 per cent may encourage irrigation use and minimize inflation in the initial stages of irrigation development; (2) assessment may be based on crop area in the interests of practicality and convenience but volumetric pricing should be promoted wherever possible, especially on tube wells; (3) in areas where farmers are not yet accustomed to irrigation, a two-part tariff may be introduced in place of the simpler single charge based on crop area; (4) irrigation rates should be uniform unless there are

Subject	Source	Description
		strong reasons to introduce variable rates, such as variations in climate, soil, irrigation systems, crop irrigation requirements, or utilization of irrigation potential. Pre-independence Indian pricing policy was based on strict adherence to financial return, but after 1947 this criterion was initially relaxed and subsequently replaced by a cost-benefit standard in order to achieve rapid development of irrigation. The result was very low water rates, heavy government subsidization and considerable diversity in the fixing of rates. Recent thinking on pricing is reviewed, with attention to quantum of water rates, mode of assessment, water rate structure and water rate uniformity diversity.
Conservation in agriculture	C.V. Gole, V.N. Amble and M.M.L. Chopra, "Rationalization of irrigation rates in a developing country", ICID *Bulletin*, vol. 26, No. 1 (January 1977) pp. 31-40 and 49	Current methods of fixing irrigation rates in India's 18 states and regions, as well as in several foreign countries, are analysed, and criteria are proposed for formulating a rational rate structure for India. The irrigation rate system adopted must balance two opposing goals: (1) to recover costs and a portion of the benefits, but (2) to provide the producer with incentive for increasing production through greater use of irrigation. It is concluded that: (1) great variation exists among the Indian states and regions in irrigation rate-setting policy, with rates fixed largely on an ad-hoc basis; (2) at the beginning of a new irrigation project it may be necessary to limit cost recovery to annual operation and maintenance expenses in order to promote irrigation use; (3) in later stages rates should be increased to recover part of the interest charges and depreciation on invested capital; (4) cost of non-state irrigation sources should be considered in setting minimum state rates; (5) benefits derived by irrigators should be measured as the excess of net benefits with irrigation compared with net benefits before irrigation; (6) as an interim measure, rates should be assessed on the basis of gross income from irrigated crops until data are available for net benefit determination; (7) rate assessment based on volumetric supply is scientific and ensures optimum water use, but administration costs are prohibitively high; (8) rates should be uniform over broad geographical areas. Several additional considerations are discussed.
Control of water on the surface	J. Queijo, "Harvesting a nuisance", *Environment*, vol. 19, No. 2 (May 1977), pp. 25-29	While mechanical, chemical and biological control efforts against water hyacinth (*Eichhornia crassipes*) continue, attention is now being directed to beneficial aspects of floating plant. Within 10 years of its introduction into the United States at a New Orleans exposition in 1884, the plant had spread to North Carolina, South Carolina, Georgia, Alabama, Mississppi and Florida. Still a major problem, water hyacinth will normally double in weight in 7-10 days, and 10 plants can theoretically multiply to 600,000 in eight months. Dense mats clog waterways, cause suffocation of fish and provide breeding grounds for disease-carrying mosquitoes and snails. Control efforts were begun in 1898 with a mechanical cropper; two years later, the 35-year reign of the deadly sodium arsenite started, finally replaced in 1937 with use of a crusher boat.

Subject	*Source*	*Description*
		The herbicide 2, 4-D, first used in the mid-1940s, to date is the most effective chemical control agent. Natural predators, including water hyacinth weevils and a water snail, are being tested. Water hyacinth can absorb nutrients and chemicals from sewage and industrial wastes at high rates, and a sewage treatment plant has been started in Mississippi using the plants to remove nitrogen and phosphorus, with production of methane and fertilizer as by-products. Research is under way to convert hyacinths into cattle feeds. Three kg dried hyacinth can supply a steer with daily nutritional requirements of calcium, phosphorus, potassium, magnesium and sodium.
Effects of pollution	Georgia Department of Natural Resources, Atlanta, Georgia, "The environmental impact of freshwater wetland alterations on coastal estuaries", Conference Report, Technical Planning Seminar, held at Savannah, Georgia, on 23 June 1976, p. 85	In order to provide a forum to review the environmental impact of freshwater wetland alterations on coastal estuaries, a coastal resource planning seminar was held at Savannah, Georgia on 23 June 1976. Seminar papers emphasized relationships observed between freshwater wetlands and estuarine values, and the use of such data for coastal planning and management. Four of the five papers are case studies about interactions between the freshwater ecosystems and estuaries. Results of the studies show that freshwater ecosystems benefit marshes and estuaries by: (1) assimilating and altering pollutants which would otherwise harm estuarine fish and wildlife; (2) regulating freshwater flow into the estuaries, and hence creating proper environmental conditions for fish and wildlife, and also preventing downstream flooding during heavy storms; and (3) regulating a flow to the estuary of nutrients and other minerals, some of which are essential to the nearshore and offshore productivity. One paper is concerned with integrating scientific data into environmental planning analysis. The paper suggests application of scientific data descriptive of a system under evaluation to the alternative models designed to solve a particular planning problem. A model that maximizes the benefits and minimizes the costs to the existing ecosystem should be selected as the solution to a problem.
Effects of pollution	E.J. Martin, and L.W. Weinberger, "Eutrophication and water pollution". Available from the National Technical Information Service, Springfield, Virginia 22161, as PB-254 271 (1966)	The nature of accelerated eutrophication, its extent in the United States and means of control are discussed. Naturally-occurring eutrophication may succeed oligotrophy following the birth of a lake, but increased availability of nutrient material may stimulate biological production and promote premature lake aging. Accelerated eutrophication may be defined as the state of a body of water resulting from the intentional or unintentional, natural or man-made modifications to the aquatic environment to the extent that the ecological system supports an imbalance in biological production, which creates a nuisance or interferes with water use. A discussion of nutrient characteristics is presented, and includes tables of eutrophic waters in the United States, abundance of algae in American rivers, and the most common nuisance algal species. Some human activities which increase nutrients in waters are: (1) discharge of inadequately treated sewage and industrial wastes;

Subject	*Source*	*Description*
		(2) improper agricultural and other watershed practices; and (3) canalization of streams. A detailed evaluation of eight nutrient removal systems is given: (1) activated sludge; (2) algal removal systems; (3) chemical precipitation; (4) ion exchange; (5) ammonia stripping; (6) electrodialysis and other membrane processes; (7) effluent spraying on land; and (8) distillation. Tables summarize removal rates for each process.
Effects of pollution	L. Obeng, "Should dams be built? The Volta Lake example", *AMBIO*, vol. 6, No. 1 (1977) pp. 46-51	Environmental and societal effects of the creation of such impoundments as Volta Lake in Ghana are evaluated. Given the critical developmental importance of large dam projects for hydroelectric power and water storage in many parts of the world, dam construction is unavoidable and major attention must therefore be focused on minimizing negative effects. Volta Lake, created in 1964, is currently the world's largest freshwater impoundment, with a shoreline of 4,800 km, an area of 8,500 sq km, and an estimated capacity of 165 cu km, and a depth range of 19.75 m. Primarily physical and ecological changes included: (1) the residential displacement of 80,000 persons; (2) high turbidity and greatly reduced transparency (as low as 10 cm) resulted from large quantities of suspended, dissolved, and colloidal organic matter; (3) a decreasing surface-to-bottom temperature gradient and mixing of waters, with no persistent stratification; (4) low chemical ion load; (5) well-developed plankton and invertebrate populations; (6) the spread of aquatic weeds; and (7) an increase in urinary schistosomiasis. Many objectives have been met, including fisheries, water supply, irrigation, electricity production, destruction of breeding grounds of the *Simulium damnosum* fly and transportation.
Effects of pollution	H.D. Payer, K.H. Runkel, P. Schramel, E. Stengel and A. Bhumiratana, "Environmental influences on the accumulation of lead, cadmium, mercury, antimony, arsenic, selenium, bromine and tin in unicellular algae cultivated in Thailand and in Germany", *Chemosphere*, vol. 5, No. 6 (1976) pp. 413-418	Relative inputs of heavy metal to the edible chlorophyte alga *Scenedesmus obliquus* by various sources were determined for polluted and unpolluted environments in Federal Republic of Germany and Thailand. Tests conducted in 1972-1973 in rural areas of Chieng Mai and Bangkok, Thailand, and in agricultural areas of Dortmund, Federal Republic of Germany examined the role of atmospheric dust, rainfall, water quality and fertilizers. Algae were grown outdoors under natural climatic conditions, simulating a model agricultural crop. Twice as much lead was found in algae from industrialized Bangkok than from Chieng Mai, a rural district 700 km from Bangkok, while the lead content of algae from Dortmund was six times that of Chieng Mai. Direct determination of dust fallout lead content showed that lead inputs were the results of air pollution. Superphosphate fertilizers accounted for about 50 per cent of the cadmium, tapwater 25 per cent, dustfall 15 per cent and rainwater 10 per cent. Fertilizers were also the main source of arsenic, cadmium and selenium in Dortmund samples, whereas tapwater was the main source of bromine, mercury and tin, and air pollution was the primary contributor of lead and antimony.

Subject	*Source*	*Description*
Effects on water of man's non-water activities	H.W. Anderson, M.D. Hoover and K.G. Reinhart, "Forests and water: effects of forest management on floods, sedimentation, and water supply", Pacific South-west Forest and Range Experiment Station, Berkeley, California, General Technical Report PSW-18 (1976), p. 115	A summary is presented on the forest's influence on water resources, particularly the effects of current forestry practices. Four types of wetland forests are discussed. (1) *Wet flats.* Most efforts in water management are concentrated on wet flats supporting pines. One current practice is to remove surface water and lower ground water to increase trafficability of heavy equipment. (2) *Bay, or upland bogs* typically produce little timber, water, forage and wildlife. Not enough is known about the hydrochemical processes of the infertile soil to recommend measures to improve forest growth. Logging may increase water levels enough to endanger regeneration. (3) *Swamps and upland ponds.* Removal of surface water can kill older trees and destroy wildlife habitat. These values can be enhanced by installing dikes and water control structures. (4) *Bottomlands* are productive because of inherent fertility and abundant moisture. Uncontrolled drainage adversely affects stand composition, tree growth and regenerative potential. Current water management consists of a kind of flood irrigation. Hydrologic consequences of management of wetland forests have been little studied and are poorly understood.
Estuaries	D.D. Barile, "Hydrologic and environmental effects of long-term drainage on a coastal area (case study: Melbourne Tillman Drainage District, Palm Bay, Florida)", the Environmental Impact of Freshwater Wetland Alterations on Coastal Estuaries, held at Savannah, Georgia, on 23 June 1976, *Conference Papers*, pp. 47-59	Operations of the Melbourne Tillman Drainage District (MTDD) Palm Bay, Florida, were used for an analysis of consequences of large-scale and long-term drainage from wetlands into estuaries. A 98 m^2 area of the St. Johns River marsh has been drained by MTDD since 1923. Water is carried by a 200 m grid of canals through a drainage divide and introduced into the Indian River estuarine lagoon by way of a natural stream, Turkey Creek. Systems analysis was used to define changes in the area from 1900 to 1975 and to investigate effects of a future drainage plan. Effects of drainage and population growth were noted in the upland, the coastal area and in the estuary. The incidence of fire increased as water was removed from marshes. Marshes were reduced in size, prairies were replaced by pine lands and recently introduced exotics replaced native growth. The amount of water stored in the shallow ground aquifer has decreased by 13 per cent. The amount of water flowing through Turkey Creek has increased from 5 per cent rainfall to 28 per cent, thus decreasing the salinity and destroying the productive shellfish beds. Water entering the estuary has decreased in quality through the additional nutrient and sediment loading from the sewer discharge and through the reduced time period that the water spent in the upland sloughs, swamps and marshes. Planners in coastal areas face two problems: (1) drainage and flood protection; (2) water supply and prevention from salt water encroachment during drought conditions.
Estuaries	R.W. Sheldon, W.H. Sutcliffe, Jr. and M.A. Paranjape, "Structure of pelagic food chain and relationship between plankton and fish production", *Journal*	The simplified view of the pelagic food chain, based essentially on particle size spectra, shows that by considering the interactions of organisms relative to their size it is possible to arrive at a plausible structure for the pelagic food chain. From this, estimates of plankton

Subject	*Source*	*Description*
	of the Fisheries Research Board of Canada, vol. 34 (1977), pp. 2344-2353	and fish production are derived. Phytoplankton production is estimated from fishery production for the Gulf of Maine and the North Sea and fishery production is estimated from plankton production for an area of Peru.
Estuaries	C.A. Siegfried, A.W. Knight and M.E. Kopache, "Ecological studies in the western Sacramento-San Joaquin delta during a dry year". Available from National Technical Information Service, Springfield, Virginia 22161, as PB-279665 (January 1978)	A portion of the Western Sacramento-San Joaquin delta was studied by the University of California (Davis) Estuarine Research Group during 1976, a critical dry year. Particularly important to the ecology of the delta in 1976 was the low outflow, the fourth lowest on record. The most important aspect of water quality during 1976 was salinity incursion accompanying low flows. The low flows caused the entrapment zone to be located upstream from Chipps Island during much of 1976. The location of the entrapment zone in the San Francisco Bay estuary is thought to be very important in the ecology of the delta. The benthic community of the western delta was dominated by the Asiatic clam (*Corbicula manilensis*), *oligochaeles*, the amphipods *Corophium stimpsoni* and *C. spinicorne* and a spionid polychaete, *Boccardia ligrerica*. These taxa averaged 98 per cent of the total benthic macroinvertebrates collected at each study site. Changes in benthos composition are thought to be related to salinity incursion and changes in substrate composition resulting from the deposition of fine sediments during summer. In general, the upstream channel stations had higher standing crops of benthos than the other stations in the study area in 1976. Total benthic standing crop was lowest near Chipps Island. The standing crop peaked in June and was lowest in November.
Evaluation process	D.A. Bella, "Environment, technology and future generations". Available from National Technical Information Service, Springfield, Virginia 22161, as PB-279 605 (January 1978)	Environmental strategies involve comprehensive and broad outlooks. In contrast, environmental tactics involve more limited concerns which can usually be addressed in a disciplinary or multidisciplinary manner. The development of strategies necessitates interdisciplinary and transdisciplinary outlooks. Such outlooks are extremely difficult to achieve because different "structures of reasoning" are found to conflict with each other and confusion and disagreements result. Environmental strategies must accommodate such confusions. They must recognize and accommodate the high levels of ignorance involved in the prediction and appreciation of complex and long-term technological impacts. A strategy is proposed which encourages an adjusting, learning and creative approach to the future rather than an approach which is ultimately based upon prediction and control. The approach is described through a set of five commitments which are intended, not as absolute rules, but as attitudes or considerations which should have increased influence upon decisions. A number of applications and examples are briefly discussed.
Evaluation process	J.A. Hanson, "Towards an ecologically-based economic philosophy", *Environmental Conserva-*	The present world economic order is one which fails to recognize the finiteness of global resources and limits of the global ecosystem to absorb wastes. As this order

Subject	Source	Description
	tion, vol. 4, No. 1 (1977), pp. 3-10	continues, the threshhold of economic energy recovery will reach a point where the amount of energy and materials needed to exploit the low-grade energy resources will exceed the net energy produced by these same resources. There are two alternatives to this problem: (1) an abrupt end to the present population level and material abundance; (2) a new global economic order based on recognition of the finiteness of this planet. Should the new economic order succeed, its viability will depend on the complementarity of efficient energy conversion and conservation of negantropy (trend towards higher levels of organization). The extent to which the civilization can conserve its negantropy will determine the amount of energy available for the non-productive activities related to a continuation of progress. The attainment of the new global economic order will require a move away from centralization and megagrowth of urban/industrial complexes towards a proliferation of moderate-size, semi-self-sufficient agri-industrial communities relying primarily on technology for wider communication. Such an approach would have the following advantages: (1) conservation of transportation energy; (2) facilitation of recycling; (3) decreases in community management problems; (4) stimulation of geothermal, ocean-thermal, wind and solar energy usages.
Evaluation process	C.W. Howe, "The effects of water resource development on economic growth: the conditions for success", *Natural Resources Journal*, vol. 16, No. 4 (October 1976), pp. 939-955	Successful transfer of Western water development technology to the third world depends on four conditions only rarely present: (1) that water is the real bottleneck to growth; (2) that capital is available; (3) that institutions exist which can manage the technology; and (4) that the technology fits the local social structure and values. Specific cases where water is a bottleneck are discussed, along with the relative importance of water to growth in various activities. Case studies are given for water development projects in Kenya, Mexico, Arizona, the Middle East, the Arkansas River, Uganda and Ghana. It is concluded that: (1) the relative importance of wate. services will change with growth; (2) water development has the most impact in early stages of growth owing to the importance of agriculture; (3) provision of all requisite complementary inputs can result in high productivity and growth effects; (4) irrigation is a necessary but not sufficient condition for agricultural growth in arid and semi-arid areas; (5) in mixed economies private sector investment response to public water project investment is a critical factor in determining total social returns; and (6) the availability of low-cost hydroelectric power is a strong attraction to the power-intensive metallurgical and chemical industries.
Evaluation process	R.S. Schulz, "Water use rates for rural water systems". Available from National Technical Information Service, Springfield, Virginia 22161, as PB-279 618 (1975)	Rural water system use rates in Iowa were computed to predict livestock needs and ascertain rural domestic use patterns. Nomographs predicted livestock water use based on animal weight and environmental temperature; average gallons/capita/day value contributing to the domestic water requirements were determined.

Subject	*Source*	*Description*
		General trends in the daily occurrence of peak flows were established. Uniform water use indicated the distribution patterns ascertained in line test sections were representative of patterns for all consumers. Use rates data showed that Iowa rural water is not being used in quantities predicted by design criteria; differences are attributed to the effect of metered water, the associated cost of metered water and farmers' reluctance to abandon the farm wells. Peak use periods were spread out over a longer span than is normally seen in high density residential areas, probably because of livestock feeding operations. Higher peaking factors were observed in the testing than those used for design of water systems meeting residential, industrial and commercial water requirements. Comparison of data obtained with simultaneous peak demand curves used for the design of other systems showed that recorded peak rates fell short of values read from Kansas data. Nomographs indicating livestock water consumption developed from data in the literature are higher than water requirements based on animal weight and average environmental temperature; they are recommended, therefore, for use for the range indicated, with special consideration for simultaneous peak demands and storage requirements.
Evaluation, processing and publication	C.T. Haan, "Statistical methods in hydrology", Ames, Iowa, The Iowa State University Press (1977), p. 378	The random variability of such hydrologic variables as streamflow and precipitation has been recognized for centuries. The general field of hydrology was one of the first areas of science and engineering to use statistical concepts in an effort to analyse natural phenomena. The purpose of this book was to enable engineers and hydrologists to apply better statistical methods to hydrologic problems through a knowledge of the methods, their foundations and their limitations. Subject areas covered included basic concepts of probability and probability distributions, properties of random variables, some discrete probability distributions and their applications, normal distributions, some continuous probability distributions, probability plotting and frequency analysis, confidence intervals and hypothesis testing, simple linear regression, multiple linear regression, correlation, multivariate analysis, data generation, analysis of hydrologic time series and some stochastic hydrologic models. This is not a statistical "cookbook" for hydrologists. Basic statistical concepts are discussed and illustrated in enough detail so that one can develop his own computational procedures or models.
Ground-water management	D.A. Davis, "Record of groundwater exploration and development, 1975-1976, Moen, Truk, Eastern Caroline Islands", Geological Survey, Honolulu, Hawaii, open-file report 77-739 (September 1977)	The exploration for and development of ground-water described in this report consisted of the drilling and testing of 22 holes and the conversion of 8 of the holes into production wells on the island of Moen, Truk Islands, during the period November 1975 to July 1976. The objective of the programme was to find sources of water to provide an improved supply for the reservoirs and pipelines of the Moen water system. The bulk of the report consists of records collected at the drilling

Subject	Source	Description
		sites during drilling and testing. Given for each test hole are a description of the drilling operation, a record of development of the hole, a record of each pumping test and a log of the hole giving a summary description of rock units penetrated by the bit. For wells, there are records, where they are available, of the reaming of test holes to production-well diameter; data on casing, screens, gravel pack and grout seal; and records of pumping tests.
Ground-water management	B.E. Lofgren, "Hydrogeologic effects of subsidence, San Joaquin Valley, California", in *Proceedings of the Anaheim Symposium, December 1976,* International Association of Hydrological Sciences publication No. 121 (1976), pp. 113-123	Subsidence has slowed in most of the San Joaquin valley, California, site of one of the most extensive man-made subsidences in the world. After 40 years of ground-water overdraft, canal imports have generally reversed declining water-level trends. As of 1976, artesian heads have recovered towards presubsidence levels, and subsidence rates have decreased from an earlier maximum 0.5 m/yr to near zero in much of the valley. Increasing irrigation demands, particularly during years of deficient precipitation, pose the threat of increased pumping and another cycle of widespread land subsidence. Because of significant hydrogeologic changes during the 1930-1970 overdraft period, however, the ground-water basin will respond differently during a second cycle of overdraft. The close correlation between water-level decline, compaction of the aquifer systems and land subsidence has been precisely monitored in the San Joaquin valley for two decades. From these data, both the elastic and the "virgin" inelastic stress-strain characteristics of the unconsolidated valley deposits and the response of the aquifer system to prolonged cyclic pumping overdraft have been determined.
Ground-water management	University of California at Davis, Water Resources Center, and California State Department of Water Resources, Sacramento, "Proceedings of the Eleventh Biennial Conference on Groundwater". Available from the National Technical Information Service, Sprinfield, Virginia 22161, as PB-279 669 (November 1977)	This conference, held at Fresno on 15 and 16 September 1977, concentrated on ground-water and ground-water management in California. Many aspects of ground-water management are examined including water rights, legal aspects, storage, public policy, recharge and conjunctive use of ground-water and surface water.
Hydraulics	R.B. Robinson, "Cost optimization of rural water systems". Available from National Technical Information Service, Springfield, Virginia 22161, as PB-279 619 (1975)	A method was developed and demonstrated for optimizing a rural water distribution system in Iowa. The method described achieves the least cost design or the optimal design for certain portions of such a system, which is generally and uniquely unlooped or dead end; linear programming and engineering judgement are the combined techniques used. The variables which can be considered by this approach are the pipe diameter, pipe pressure rating, pressure-reducing valve setting and location, and pumping head or water tower height. These variables are considered for a minimum pressure to be met throughout the system and for several maximum pressures for pipe classes and service lines. The solution

Subject	*Source*	*Description*
		obtainable by the procedure is considered closer than that produced by conventional design techniques. The method was demonstrated successfully on a simple distribution system. Recommendations are made for refinement of the optimization method, development of a computer programme for distribution and eventual application of linear programming to looped distribution systems.
Hydraulic machinery	R.K. Clayton, "Photosynthesis and solar energy conversion". Available from National Technical Information Service, Springfield, Virginia 22161, as BNL 50530 (March 1977)	A study of potential uses of photosynthesis for energy production is included in the proceedings of the Brookhaven National Laboratory Symposium, "Chlorophyll-Proteins, Reaction Centres and Photosynthetic Membranes". Energy sources stemming directly or indirectly from solar origin which might become important in the United States include: (1) wind-powered turbines; (2) ocean thermal gradients (heat engines); (3) direct solar heating (heat engines or chemical reaction cycle producing hydrogen from water); (4) photosynthetic systems (growth of plants, including algae, and conversion to fuels, or photosynthetic hydrogen production); and (5) photoelectric devices, possibly using materials derived from photosynthetic tissues. Sunlight offers our best long-term hope for an inexhaustible source of pollution-free energy and the most practical schemes utilize direct heating and wind power. Costs of silicon photovoltaic cells must be reduced if such cells are to be competitive. Conversion of organic waste and plants into fuel is practical, but demands exceed supply. Use of photosynthetic tissues in special ways appears highly visionary, but worthy of investigation. Energy reserves in the United States are estimated as follows: current oil and gas, less than 10 years; total oil and gas, 100 years; fission, less than 100 years; coal and oil shale, more than 1,000 years; geothermal, more than 100 years; fusion, one million to one trillion years; and solar, more than one trillion years.
Hydraulic machinery	J.A. Mungovan, "Trends emerge, but solar design options still open", *Modern Metals*, vol. 33, No. 10 (26 November 1977), pp. 22-24	A new plant for waste water treatment in Wilton, Maine, will obtain most of its energy requirements from solar collectors located on the southern exposure of the plant and from methane generated by the treatment processes. Because of federal and state participation, payback to Wilton will take about wto years; the plant would require about 18 years to pay for itself without aid. The $2 million plant will use 54-double-glazed, copper-and-aluminium flat plate collectors supplied by Grumman Energy Systems. The energy demand of the equipment is low and the plant is designed so as to minimize heat loss. Fuel cost savings are expected to amount to $3,594 annually; electricity cost savings should be $875 each year. This application of solar energy won the Owens-Croning Fiberglass Corporation Energy Conservation Award for 1975. Grumman Energy System's aluminium flat plate collector can be used interchangeably with its copper-and-aluminium flat plate collector in some applications.
Identification of	C.E. Boyd, "Effluents from cat-	Samples of effluents from eight channel catfish ponds

Subject	*Source*	*Description*
pollutants	fish ponds during fish harvest", *Journal of Environmental Quality*, vol. 7, No. 1 (January-March 1978), pp. 59-62	at Auburn, Alabama, collected during fish harvest, were analysed for biochemical oxygen demand (BOD), chemical oxygen demand (COD), settleable matter, soluble orthophosphate, total phosphorus, total ammonia and nitrate. Settleable matter concentrations, for which 3.3 ml/litre has been suggested as the instantaneous maximum for effluents from fish ponds, ranged from 0 to 1.2 ml/litre during the draining phase when 95 per cent of water was discharged. Water discharged during seining to remove fish usually contained greater than 3.3 ml/litre settleable matter (range 0.5 to 100 ml/litre). Concentrations of other potential pollutants, except nitrate, also increased during the seining phase. However, even effluents discharged during the draining phase had higher levels of most measured parameters than first-order streams draining forested or agricultural watersheds in the vicinity.
Lakes	V. Benech, J. Lemoalle and J. Quensiere, "Mortality of fish and environmental conditions in Lake Chad during a period of drought", *Cah. Orstrom Ser. Hydrobiol*, vol. 10, No. 2 (1976), (in French) pp. 119-130	During the 1972-1974 drought, Lake Chad (Chad) was split into three separate basins as a result of the water level decrease. The variations of some chemical and physical parameters are described for the northern basin and for the eastern archipelago at Bol. Mass fish mortalities were observed in both basins. They are associated with water turbulence during the decrease of the water level, but anoxia due to macrophyte decomposition is the main cause for mortalities during the annual flood at Bol. Relative catch per unit effort of some species is given. A criteria level, below which mortalities occurred, was determined for both basins. Copyright 1977, Biological Abstracts, Inc.
Sources of pollution	I.A. Klyukanova, "Organic matter in the suspended load of the rivers and irrigation systems of Soviet Central Asia", *Soviet Hydrology, Selected Papers*, vol. 15, No. 1 (1976), pp. 68-71	The general patterns of variation in the content of organic matter in the strongly calcareous suspended load of the rivers and irrigation systems of Soviet Central Asia were investigated. The variation in the content of organic matter along the length of a river was given as a function of river load, and the annual discharge of organic substances by the major rivers of this region was computed. The suspensates were sampled in the period 1963-1973 in almost all the major rivers of Soviet Central Asia during the flood peak, and in the largest irrigation systems. Data on the absolute content of organic matter, obtained by multiplying the suspended particle concentration in the water, sediment discharge, and its volume by percentage content of organic matter, were presented. Study of the changes in the chemical composition of the suspended load of rivers (including organic matter) and irrigation-water suspensates has become one of the pressing problems in the geochemistry of suspensates. A successful solution of this problem probably will make it possible to use data on the changed chemical composition of suspended and irrigation sediments in a sound forecast of the probable changes in the agrochemical, physicochemical and other properties of irrigated lands.
Sources of pollution	S.P. Larson, S.S. Papadopulos, H.H. Cooper, Jr. and W.L.	Evaluation of the Wailuku-Kahului wastewater treatment facility, near Kahului, Maui, Hawaii, required

Subject	*Source*	*Description*
	Burnham, "Simulation of wastewater injection into a coastal aquifer system near Kahului, Maui, Hawaii", American Society of Civil Engineers (ASCE) *Proceedings of Hydraulics in the Coastal Zone*, College Station, Texas, 10-12 August 1977, pp. 107-116	study of the potential impact of injection of effluent into the saline-water part of a lava aquifer system. To determine the distribution of injected fluid, a computer model was constructed to enable consideration of (1) an aquifer system containing fresh and saline water; (2) heterogeneous aquifer characteristics; (3) non-uniform boundary conditions; and (4) concurrent withdrawal of saline water near the injection site. A sharp interface was assumed to exist between freshwater and saline water in the aquifer, and a numerical model was employed to simulate ground-water flow in the freshwater zone. Withdrawal of 68 cu ft/sec of saline water within 2,600 feet of the injection site was modelled analytically, and the numerical and analytical models were coupled to provide an acceptable prediction of aquifer response to injection. A simulated injection rate of 6.2 cu ft/sec resulted in a steady-stage wastewater plume extending 1,200 feet upgradient from the injection site and displacing the interface between freshwater and saline water 500 feet seaward. Three-dimensional analysis indicated that if fluid was injected into the saline-water zone and if vertical hydraulic conductivity were less than horizontal conductivity, the injected plume of wastewater would be contracted in size at the top of the freshwater zone and expanded at the bottom relative to isotropic conditions.
Streamflow and runoff	M. Chang and D.G. Boyer, "Estimates of low flows using watershed and climatic parameters", *Water Resources Research*, vol. 13, No. 6 (December 1977), pp. 997-1001	The lowest 7-day streamflows (10-year return period) of 12 Monongahela River tributaries in West Virginia were estimated from watershed and climatic parameters. Of the parameters studied, watershed perimeter alone accounted for about 88 per cent of the spatial variability of 7-day low flows in a multiple-regression analysis. Main channel length and watershed form increased the predictability to about 95 per cent. Precipitation and temperature parameters, which were highly correlated with watershed elevation and latitude, raised the R^2 to 0.999. The standard error of estimate was 7.43 cu ft/sec, or about 30 per cent of the observed mean; this result, an order of magnitude smaller than that obtained in an earlier study, suggests that meaningful low-flow estimates can be obtained from watershed parameters alone in a mountainous humid region.
Techniques of planning	F.C. Wang, H.T. Odum and M.E. Lehman, "Concepts and techniques for evaluation of energy-related water problems". Available from National Technical Information Service, Springfield, Virginia 22161, as PB-279 608 (December 1977)	Research effort is described to apply the newly evolving theory of energy analysis and the classical operational research techniques (linear programming) to a procedure that may serve the resource manager in decision making. The theory investigated involves the concepts of net energy, energy quality and energy amplifier value. Based on these concepts, an attempt was made to estimate energy values of water. One energy value of water is equal to the flow that it facilitates in a specific use. This is so because of its role as an amplifier which makes more energy available in different systems when used as a limiting factor. Another energy value is the embodied energy in forming water in processes of the biosphere or of man's activities. The energy effects may

Subject	*Source*	*Description*
		ultimately be related to embodied energy. The objective function in the linear programming analysis is structured in terms of net productivity of the subsystem measured at its boundary. The maximum power principle rather than profit maximization was used as a criterion because the system which gets the most energy and uses energy most effectively in competition with other systems will survive in the long run. Although the research effort should be further extended or modified to develop practical procedures for application, a simple hypothetical model considered representative of the major land-use subsystems is presented to illustrate such applications. Sensitivity analysis was performed to test the stability of the model and its related problem solution to a resource plan.
Ultimate disposal of wastes	O. Hockman, E. Hwang and G. Rudzitis, "The environmental costs of land-fills and incinerators". Available from the National Technical Information Service, Springfield, Virginia 22161, as ANL 76-XX-15 (July 1976)	A study of economic and environmental costs of sanitary landfills and incineration for non-hazardous municipal solid wastes in the Chicago metropolitan area concludes that total social costs of landfills are only 25 per cent as large as incineration costs. Landfill costs are lower both for (1) investment and operating costs alone, and (2) total social costs, including environmental costs. The total cost for incineration was calculated at $16.35/ton of refuse, compared with $4.32/ton for landfills. While the data pertain to the Chicago area, these conclusions may apply to other large cities. At a properly operated sanitary landfill, solid waste is [illegible]l and covered by at least six inches of earth; [illegible] not burned. Neither ground-water nor surface-water pollution should result. Capital costs are low and no sorting of waste is needed. Upon completion, the land can usually be reclaimed for golf courses, playgrounds or parking lots. Drawbacks include the need for large land tracts, political jurisdiction problems and transportation costs increasing with distance from the landfill. Incineration (including residue disposal) requires much less land and can be located nearer the area served, but capital land-operating costs are considerably higher. Skilled personnel and dust and ash control devices are required. For environmental and economic cost comparisons in this study, 55 landfill sites and eight incinerators were analysed. Air dispersion and damage models were employed.
Waste treatment processes	"Wasting water", *Rain*, vol. 4, No. 3 (December 1977), pp. 4-5	Separate treatment of toilet wastes and kitchen garbage of composting can reduce the extent of treatment required for the remaining greywater. Separate treatment and water-conserving measures can reduce domestic waste water treatment needs sufficiently to allow the use of simple treatment systems installed and maintained by the homeowner. These simple systems can cost much less than central septic-leach systems. They typically return water to the water-table in small doses. Their disadvantages are generally related to the lack of experience and inadequate standards. Because construction standards vary widely and have a poor compliance record, regulatory agencies are usually reluctant to accept these systems. Treatment requirements for

Subject	*Source*	*Description*
		greywater are generally dependent upon the waste water volume, its strength and the intending reuse. It is very difficult to determine the nature of health hazards associated with greywater treatment.
Water demand	K.C. Gibbs, "Price variables in residential water demand models", *Water Resources Research*, vol. 14, No. 1 (February 1978), pp. 15-18	There have been inconsistencies in past residential water demand studies concerning the specification of the relevant price variable. Both average and marginal prices have been used. Households faced with the decision to expand (or contract) their water consumption are responsive to the additional cost (or savings) involved with this decision. The appropriate measure of this price is marginal price, not average price. Data were gathered from a large metropolitan area (Miami, Florida) to illustrate the divergence in estimates from two demand models, identically specified, except for the price variable. One used marginal price and the other average price. Predictions of consumption varied from 22 to 107 per cent between the two models. The average price model significantly overestimated the response of consumption to price and income changes, a result worthy of consideration.
Water demand	M.T. Katzman, "Measuring consumer surplus benefits of water supply extensions in developing countries", *Water Resources Bulletin*, vol. 14, No. 1 (February 1978), pp. 46-54	For investments in water mains serving new households, consumer surplus benefits may far outweigh those measured by revenues recouped from user fees. While consumer surplus might be capitalized in the value of sites with access to mains, empirical attempts to measure such capitalization have not proved invariably successful. An alternative technique based upon the direct estimation of the demand curve is used. An analysis of Penang Island, Malaysia, indicates that the consumer surplus benefits are one and a half times greater than the revenues recouped through user fees. The applicability of this technique to cost-benefit analysis of water supply investments is discussed. In conclusion, the estimation of consumer surplus by tracing the demand curve is feasible for systems which have accurate metering and billing procedures and which have exhibited substantial variation in water charges over time and space. For systems meeting these conditions, the calculation of the net benefits of water supply extensions by the demand curve technique is simpler than by the method of land capitalization; the demand curve technique is less general in that it applies only to priced services and it is less likely to measure the external benefits.
Watershed protection	Ecosystems International, Inc., Gambrille, Maryland, "The application of remote sensing to the development and formulation of hydrologic planning models". Available from the National Technical Information Service, Springfield, Virginia 22161, as N76-18632 (January 1976)	Three tasks were undertaken in this research effort: (1) the validation of the peak-rate model on an expanded set of watersheds; (2) the development of a routing model for complex basins; and (3) the quantitative hydrologic analysis of Landsat imagery. In the expanded validation of the peak-rate model, a 31 watershed example was selected, with significant geographic and hydrologic diversity. The prediction supplied by the model was tested for each, with this output compared to the records and to forecasts computed by using three other conventional planning models. It was

Subject	Source	Description
		discovered that different geographic regions exhibit varying seasonal properties, but that within a region, the characteristics are similar. Next, a routing model was developed which approximated the watershed by a series of strips, each having its own set of surface and rainfall parameters. The output of these strips was summed using a simple time delay function accounting for the length of overland flow and the hydrologic characteristics of the channel. It was found that both the sensitivity of runoff to the basin slope and the areal extent of rainfall were significant and should be provided for by the planning model. The final task used remote sensing directly to determine the hydrologic information content of the Landsat bands and to attempt to extract the necessary hydrologic data. It was discovered that information sufficient to determine several of the important inputs to the model could be determined from Landsat data using relatively uncomplicated visual techniques.
Water in soils	Ye. A. Bespalova, V.V. Melent'yev, Yu. I. Rabinovich and V. Yu. Rayzer, "Some results of measurements of the radio emission of soils using a highly sensitive aircraft radiometer with a 3 cm wave range", *Soviet Hydrology: Selected Papers*, vol. 15, No. 1 (1976), pp. 18-20	Some results were reported of radiothermal investigations of semi-desert and swampy regions in the lower courses of the Amu-Dar'ya and Ural rivers and of a tentative correlation-statistical analysis of these regions. In 1973, the radiothermal emission of earth covers was investigated from an IL-18 aircraft-laboratory with a 3 cm radiometer. This radiometer is a straight-amplification modulation radiometer with four tunnel diode amplifier stages. The normalized spectra of two different waterlogged areas were very similar qualitatively and also quantitatively in their high-frequency portion. In the two areas in question, the characteristic dimensions in the fields of radioluminance temperatures have distinct features: two high-frequency peaks, which correspond to features (periodicities) with characteristic dimensions of 1.2 and 1.7 km, and two lower-frequency peaks with characteristic dimensions of 2.2 and 5 km. Another important conclusion follows from analysis of these spectra: since the records were made on flights in different directions, the field of random values of radioluminance temperatures is probably spatially isotropic. The main result obtained is that statistical methods can be used to analyse the fields of radioluminance temperatures (for aircraft observations) and that they give fairly explicit and interpretable results.
Water treatment and quality alteration	J.D. Keenan and D.A. Hegemann, "Chlorination and ozonation in water and waste water treatment", *Chemosphere*, vol. 7, No. 1 (1978), pp. 9-28	An evaluation based on chemical and biological factors cited in previous studies of chlorine and ozone as disinfection agents of waste water and potable water was presented. Chlorination of potable water was effective for the removal of tastes, odours, colour, iron and manganese. Chlorine was also found to control algal growth, slime growth, and hydrogen sulfide, and to improve activated silica precipitation. Studies in which the use of chlorine in waste water treatment was shown to produce potentially toxic chlorinated organics were cited. The production of chlorinated organics in waste water was considered more serous than in potable water because of the larger number and concentrations of

Subject	Source	Description
		organics in waste water. Dechlorination was considered an expensive remedy for the effects of chlorination. Ozonation of waste water was found effective in the reduction of fecal coliform counts, odour, colour, turbidity, organic pesticides, and the conversion of cyanide to a biodegradable level. Treatment with 60 parts per million of ozone was required to reduce BOD levels; COD was reduced with more conventional ozone concentrations. Costs for ozonation and chorination of waste water appeared compatible. An analysis of the chemical reactions occurring during ozonation and chlorination was presented.
Water quality control	E.R. Gundlach, "Oil tanker disasters", *Environment*, vol. 19, No. 9, (December 1977), pp. 16-20 and 25-27	Case histories of massive oil spills from tankers and offshore drilling operations and the environmental consequences of these spills are reviewed. The impact of oil spills on the environment is highly variable. The coastal zone, with its striking biological productivity, is most likely to be severely damaged during a spill, while offshore incidents seem to cause only minor environmental impairment. The season in which the spill occurs also is influential in determining the extent of biological damage. During the spring reproductive period, a spill can be particularly injurious. The toxicity of petroleum varies greatly among crude and processed oils, depending on the hydrocarbon components. Plans and equipment for implementation in future oil spills are discussed.
Water quality control	K.S. Shumate, E.E. Smith, V.T. Ricca and G.M. Clark, "Resources allocation to optimize mining pollution control". Available from National Technical Information Service, Springfield, Virginia 22161, as PB-264 185 (November 1976)	In determining cost-effective actions to eliminate or abate acid mine drainage from coal mining operations, a computer-based model was developed to describe or predict drainage acidity from deep and surface mines and from coal refuse piles. The model can: (1) produce a time trace of acid load and flow from acid drainage sources as a function of climatic conditions; (2) generate continuous receiving stream flow data from precipitation data; (3) predict acid load and flow from mine drainage sources using precipitation patterns and watershed status typical of worst-case conditions; and (4) predict optimum resource allocation using alternative treatment methods for worst-case conditions during both wet and dry periods of the hydrologic year. Knowing the acid load from each source as a function of time, costs of alternative mine drainage treatment techniques can be estimated, together with their effectiveness in reducing unabated acid loads. Alternative cost and effectiveness estimates for the individual acid sources are then used as an input to an optimization model, which can be used to calculate the minimum costs for a given level of abatement in the watershed or the maximum water quality attainable for a given cost. In most cases, the field data required as input to the model are not currently available, and the model has not been fully tested or compared to real systems, nor has sensitivity to input data been determined.
Water quality control	J. Stein, "Water for the wealthy", *Environment*, vol. 19,	An assessment of the extent of water-borne human diseases in developing countries is followed by a dis-

Subject	*Source*	*Description*
	No. 4, (May 1977), pp. 6-14	cussion of water quality and disease control measures. Each year there are 250 million new cases of typhoid, cholera, amoebic dysentery, worm diseases, trachoma, sleeping sickness, schistosomiasis, filariasis, malaria, onchocerciasis, and other water-related diseases, and 25,000 people die from them each day. Causes are widespread and include pollution, water shortages, breeding of mosquitoes, flies and snails. As many of these diseases are chronically debilitating rather than fatal, they often go untreated because of a lack of public attention or money. Some 70 per cent of the world population is without a safe and dependable water supply, particularly in rural areas. Many water-borne diseases could be controlled with safe water supplies; washing of hands and face could virtually eliminate the incidence of trachoma, and simple waste treatment could drastically reduce fecally-transmitted diseases. In rural areas, a starting point should be a protected spring or well with a hand pump, followed as a next step by delivery of water to a public fountain or standpipe. While ground-water supplies are generally safe, when properly located, surface water often needs treatment to make it safe; simple chlorination may be sufficient. Chemical, biological and drug treatment measures are being used for disease control.
Water quality control	J.C. Wade and E.O. Heady, "Measurement of sediment control impacts on agriculture", *Water Resources Research*, vol. 14, No. 1 (February 1978), pp. 1-8	Environmental policy has been explicitly expanded in order to consider non-point or dispersed sources of water pollutants. This study utilizes a national agricultural model to evaluate hypothetical policies of sediment control viewing the problem as primarily a national one of agricultural land use. A sediment sector is added to the basic Center for Agricultural and Rural Development/National Water Assessment model to test the impacts of sediment control policies on the agricultural production system. Costs of alternative control policies are analysed; these costs are defined as the additional costs to agriculture of several alternative sediment control policies. Using linear programming, the minimum cost of the minimum feasible total sediment load is determined, a single restraint imposed at the national level.

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